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**MAINTENANCE OF LIQUID INSULATION  
MINERAL OILS AND ASKARELS**

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## **PURPOSE AND SCOPE**

Insulating liquids used in transformers, circuit breakers, and high-voltage bushings require proper testing and maintenance to keep them in good condition. Liquid insulation that is not in good condition may cause damage to equipment and become a hazard to personnel. Liquid insulation can be grouped into three broad categories, (a) mineral oils derived from petroleum, (b) nonflammable, synthetic liquids containing PCB's (polychlorinated biphenyls) commonly called askarels, or any of many trade names for askarel, and (c) several new synthetic liquids being offered as a substitute for askarel.

Gas-in-oil analysis of mineral oils can provide early detection of developing problems. If accurate information on the condition of mineral oil is available as the oil slowly deteriorates, it is possible to predict when the oil will reach the danger zone, and the most convenient time can be chosen for remedial measures to be taken. Too frequently, the testing and purifying of liquid insulation is done without due regard to certain important precautions. The purpose of this chapter is to give a better understanding of the characteristics of insulating liquids and to establish uniform maintenance practices for tests and treatment.

# CONTENTS

<u>Section</u>	<u>Page</u>
<b>Part I - Mineral Insulating Oils</b>	
1. Characteristics of insulating oil ..	1
1.1. Refining of insulating oil ..	1
1.2. Specifications for insulating oil ..	1
2. Deterioration of insulating oil ..	1
2.1. Effect of oxygen on oil ..	1
2.2. Moisture in oil ..	3
2.3. Oil deterioration in transformers ..	3
2.4. Oil deterioration in circuit breakers ..	6
3. Testing of insulating oil ..	6
3.1. Types of oil tests ..	6
3.2. Interpretation of test results ..	10
3.3. Periodic testing programs ..	10
4. Reconditioning used insulating oil ..	11
4.1. Natural precipitation ..	11
4.2. Filter presses ..	11
4.3. Cartridge filters ..	12
4.4. Centrifuges ..	13
4.5. Coalescers ..	13
4.6. Vacuum dehydrators ..	13
4.7. Electrostatic oil filter ..	13
4.8. Treatment of circuit breaker oil ..	14
4.9. Treatment of oil in tap changers ..	14
4.10. In-Service oil filtering ..	15
4.11. Limited interchangeability of oils ..	15
4.12. Disposal of oil ..	15
5. Reclaiming used insulating oil ..	16
5.1. Fuller's earth method ..	16
5.2. Activated alumina method ..	16

## CONTENTS - Continued

Section	Page
6. Oxidation inhibitors for insulating oil .....	17
6.1. Natural inhibitors .....	17
6.2. Inhibitor action .....	17
6.3. The DBPC inhibitor .....	17
7. Testing for gases in power transformers and regulators .....	19
7.1. Combustible gas analyzers .....	19
7.2. Gas-in-oil analysis .....	20
Part II - Askarels	
8. Characteristics of askarels .....	21
8.1. Liquid askarel characteristics .....	21
8.2. Design of askarel-filled transformers .....	21
9. Maintenance of askarels .....	22
9.1. Inspection .....	22
9.2. Sampling .....	22
9.3. Testing .....	23
9.4. Contamination .....	23
9.5. Reconditioning used askarel .....	23
10. Handling and disposal of askarel .....	24
10.1. Safety precautions .....	24
10.2. Records and monitoring .....	24
10.3. Marking of PCB's and PCB items .....	25
10.4. Disposal procedures and services .....	27
Part III - Synthetic Insulating Liquids	
11. Silicone oil .....	29
12. Retrofilling transformers with silicone oil .....	29

# CONTENTS - Continued

<u>Section</u>	<u>Page</u>
<b>Appendix A - Sampling Procedures</b>	
A-1. Sampling oil from transformers and circuit breakers for physical tests .....	31
A-2. Taking oil samples for gas-in-oil analysis .....	32
A-3. Taking gas samples for gas chromatograph analysis .....	33
A-4. Sampling oil from drums or shipping containers .....	35
A-5. Shipping .....	35
<b>Appendix B - Dielectric Test Equipment and Methods</b>	
B-1. General .....	36
B-2. Dielectric test - ASTM D 877 (Disk Electrodes) .....	36
B-3. Dielectric test- ASTM D 1816 (VDE Electrode) .....	39
<b>Appendix C - Acidity Test Equipment and Methods</b>	
C-1. Field test procedure for neutralization number (acidity) .....	40
<b>Appendix D - IFT Test Equipment and Methods for Field Use</b>	
D-1. The IFT test of oil by the drop-weight method (ASTM D 2285) .....	44
D-2. Detailed explanation of PTA model 6 tensiometer .....	44
<b>Appendix E -Doble Tests of Liquid Insulation With MH and M2H Test Sets</b>	
E-1. General .....	50
E-2 Oil .....	51
E-3. Askarel .....	52
<b>Appendix F - Diagnostic Criteria for Gas-in-oil Analysis of Transformer Insulating Oil</b>	
F-1. General .....	53
F-2. Transformer problems .....	53
F-3. Background .....	53
F-4. Diagnostic criteria .....	54

# CONTENTS - Continue

<u>Section</u>	<u>Page</u>
<b>TABLES</b>	
1	Chemical and physical characteristics of insulating oil ..... 2
2	Effective DBPC antioxidant concentration of IMPRUVOL 20 (Koppers Co.) ..... 18
3	Quantitative testing for combustible gas ..... 20
4	Manufacturers' names used for PCB's ..... 21
<b>FIGURES</b>	
1	Relation between dielectric strength and amount of emulsified water in material oil ..... 4
2	Maximum amount of water dissolved in mineral oil as affected by temperature ..... 5
3	Relation between service life, interracial tension, and acidity in mineral oil ..... 7
4	Standard PCB mark ..... 26
5	Small PCB mark
A-1	Oil sampling of electrical equipment ..... 33
C-1	A Gerin test kit with two bottles of neutral solution, four glass mixing cylinders, and seven ampules of KOH solution ..... 40
C-2	Equipment for determining acidity (neutralization number) by the Service modified Gerin test method ..... 41
D-1	The model 6 PTA interracial tensiometer mounted in support stand ..... 44
D-2	Dismantled tensiometer ..... 45
D-3	Tensiometer with 50-mL beaker under the tubing orifice ..... 45
D-4	Technique for filling tensiometer barrel with distilled water ..... 46
E-1	Liquid-insulation cell with metal carrying pail ..... 50
E-2	Liquid-insulation cell connected for testing ..... 51
F-1	Gas volume limits used in interpretation of gas chromatograph analysis for transformer insulating oil ..... 55
Bibliography ..... 56	

# PART I - MINERAL INSULATING OILS

## 1. CHARACTERISTICS OF INSULATING OIL

### 1.1. REFINING OF INSULATING OIL.-

**1.1.1. Acid refining.-** Prior to mid-1973, insulating oils used by Reclamation were produced by acid refining of naphthanic crudes. Basically, acid refining removes undesirable components from the oil by using sulfuric acid to cause the impurities to form sludge. The acidic sludge is subsequently removed by a centrifuge; sulfonic and naphthanic acid salts are removed by neutralization; water and alcohol are removed by a stream "stripper;" and remaining polar contaminants are removed by a final Fuller's earth treatment. This process is costly, and disposal of the sludge has caused environmental concern and criticism. Environmental pressures have forced refiners to curtail acid refining and develop new refining techniques.

**1.1.2. Hydrogen and solvent refining.-** Presently, two types of refining, hydrogen, and solvent are being utilized by several refiners. These methods are less wasteful potentially cheaper, and involve fewer environmental problems than acid refining.

**1.1.3. Artificially inhibited oils.-** Of concern in the use of hydrogen-and solvent-refined insulating oils is the lack of experience and information on aging characteristics of oil in service, particularly as pertains to the

formation of sludge. For this reason, Reclamation now permits the addition of an artificial oxidation inhibitor (DBPC, discussed in [subsection 6.3](#)) to new oil.

**1.2. SPECIFICATIONS FOR INSULATING OIL.-** A tabulation of the ASTM Specifications D-3487 listing of test methods and test limits for chemical and physical characteristics of oil is shown ([table 1](#)) for inhibited and uninhibited insulating oil. Reclamation uses these specifications for insulating oil for new equipment, except the DBPC content must be a minimum of 0.15 percent resulting in a range of 0.15 to 0.30 percent. These data may also be used in preparing specifications for replacement or makeup oil. [Table 1](#) is revised periodically to keep current; therefore, be sure to use the latest revision. The table shown is the 1988 version.

## 2. DETERIORATION OF INSULATING OIL

**2.1. Effect of Oxygen on Oil.-** Moisture contamination is one of the most common causes of deterioration in the insulating quality of oil. This contamination can be eliminated by purification. A less rapid but more serious characteristic deterioration, the formation of acids and sludge, is caused by oxidation. Thus, the exclusion of oxygen is of prime importance. In open-breather transformers, the oxygen supply is virtually unlimited and oxidative deterioration is consequently

**Table 1. - Chemical and physical characteristics of insulating oil**

Property	Limit		ASTM Test
	Type I	Type II	Method
Physical:			
Aniline point, EC	(63-84) <sup>A</sup>	(63-84) <sup>A</sup>	D 611
Color, max	0.5	0.5	D 1500
Flash point, mtn, EC	145	145	D 92
Interfacial tension at 25 EC, min, dynes/cm	40	40	D 971
Pour point, max, EC	-40 <sup>B</sup>	-40 <sup>B</sup>	D 97
Spec f c gravity, 15 EC/15 EC max	0.91	0.91	D 1298
Viscosity, max, cSt (SUS) at:			
100 EC	3.0 (36) <sup>C</sup>	3.0 (36) <sup>C</sup>	D 445 or D 88
40 EC	12.0 (66) <sup>C</sup>	12.0 (66) <sup>C</sup>	
0 EC	76.0 (350)	76.0 (350)	
Visual examination	clear and bright	clear and bright	D 1 524
Electrical			
Dielectric breakdown voltage at 60 Hz:			
Disk electrodes, min, kV	30	30	D 877
VDE electrodes, min, kV 0.040-in. (1.02-mm) gap	28 <sup>D</sup>	28 <sup>D</sup>	D 1816
0.080-in. (2.03-mm) gap	56 <sup>B</sup>	56 <sup>D</sup>	
Dielectric breakdown voltage, impulse conditions			D 3300
25 EC, min, kV, needle negative to sphere grounded,	145 <sup>A,E</sup>	145 <sup>A,E</sup>	
1-in. (25.4-mm) gap			
Gassing tendency, <sup>F,G</sup> max, $\mu$ L/min	+15 +30	+1 5 +30	D 2300 (Procedure A) D 2300 (Procedure B) D 924
Dissipation factor (or power factor), at 60 Hz max, %:			
25 EC	0.05	0.05	
100 EC	0.30	0.30	
Chemical:			
Oxidation stability (acid-sludge test)			D 2440
72 h:			
% sludge, max, by mass	0.15	0.1 <sup>A</sup>	
Total acid number, max, mg KOH/g	0.5	0.3 <sup>A</sup>	
164 h:			
% sludge, max, by mass	0.3	0.2 <sup>A</sup>	
Total acid number, max, mg KOH/g	0.6	0.4 <sup>A</sup>	
Oxidation stability (rotating bomb test), min, minutes	---	195	D 2112
Oxidation Inhibitor content, max, % by mass	0.08	0.3	D 1473 or D 2668 <sup>H</sup>
Corrosive sulfur	noncorrosive		D 1275
Water, max. ppm	35	35	D 1533
Neutralization number, total acid number, max, mg. KOH/g	0.03	0.03	D 974
PCB content, ppm	not detectable	not detectable	D 4059

<sup>A</sup> The value shown represents current knowledge. Work is in progress to reaffirm the validity of this value.

<sup>B</sup> In certain sections of the United States and Canada, it is common practice to specify a lower or higher pour point, depending upon climatic conditions.

<sup>C</sup> At the temperature previously used for insulating oil viscosity determinations, these values correspond to 3.1cSt (36.5 SUS) at 210 °F (98.9 °C) and to 13.0 cst (70 SUS) at 100 °F (37.8 °C).

<sup>D</sup> These limits by Method D 1816 are applicable only to new oil which has been filtered, dehydrated, and degassed.

<sup>E</sup> Currently available oils vary in impulse strength. Some users prefer oil of a 145 kV minimum for certain applications, while others accept oil with impulse strength as low as 130 kV for other applications.

<sup>F</sup> Specification requires that insulating oils meet the gassing tendency limits as measured by Method D 2300 either Procedure A or B. the specification does not require that insulating oils meet gassing tendency limits as measured by both Method D 2300 Procedures A and

<sup>G</sup> In the gassing tendency test in Method D 2300 Procedures A and B, the test temperature should be 80 °C with a test voltage of 12 kV for Procedure A and a test voltage of 10 kV for Procedure B.

<sup>H</sup> Both 2,6-ditertiary-butyl para-cresol and 2,6 ditertiary butylphenol have been found to be suitable oxidation inhibitors for use in oils meeting this specification. Preliminary studies indicate Method D 2668 is suitable for determining concentration of either inhibitor or their mixture. Method D 1473 is suitable for determining concentration of 2,6 ditertiary-butyl para-cresol, but its applicability to 2,5-ditertiary butylphenol is still under investigation.



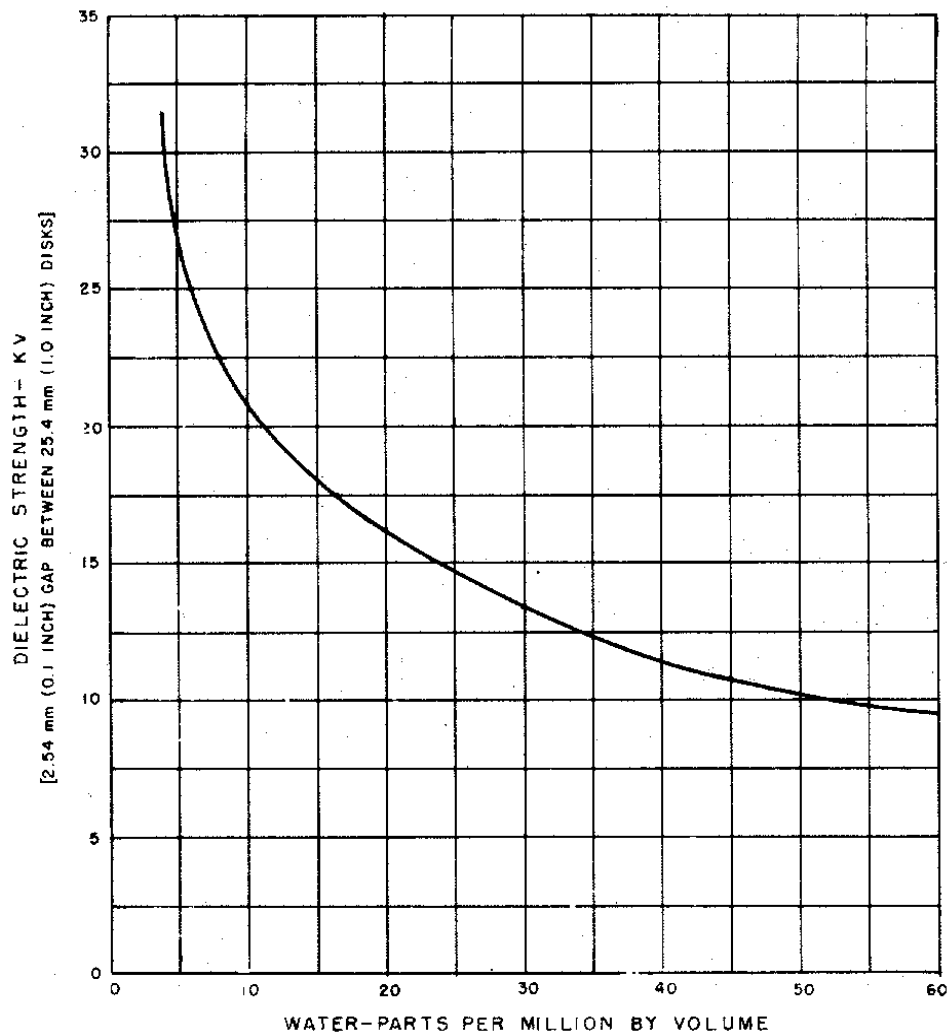
faster than in sealed transformers. Atmospheric oxygen is not the only source of oxygen available for oxidation of insulating oils; water also serves as a source of oxygen and, therefore, leaky gaskets constitute a very real hazard due to both oxidation and moisture contamination. The rate of oxidation also depends on temperature of the oil; the higher the temperature, the faster the oxidative breakdown. This fact points to the importance of avoiding overloading of transformers, especially in the summertime. Oxidation results in (a) the formation of acids in insulating oil, and (b) the formation of sludge.

**2.2 MOISTURE IN OIL.-** Water can be present in oil (a) in dissolved form, (b) as tiny droplets mixed with oil (emulsion), or (c) in a free state at the bottom of the container. Demulsification occurs when tiny droplets unite to form larger drops which sink to the bottom and form a pool of free water. Emulsified water or water in the free state may be readily removed by filtering or centrifugal treatment; the filtration process can partially remove dissolved water if filter papers are thoroughly dried before filtration and are replaced frequently.

The effect of moisture on insulating properties of oil depends upon the form in which moisture exists. A very small amount of emulsified water has a marked influence in reducing dielectric strength of oil ([fig. 1](#)) whereas dissolved water has little or no effect on dielectric strength.

**2.2.1. Effect of temperature on moisture.-** The amount of moisture which can be dissolved in oil increases rapidly as oil temperature increases ([fig. 2](#)). Therefore, an insulating oil purified at too high a temperature may lose a large percentage of its dielectric strength on cooling because dissolved moisture is then changed to an emulsion. Recommended temperatures for purifying oil are given in [section 4](#).

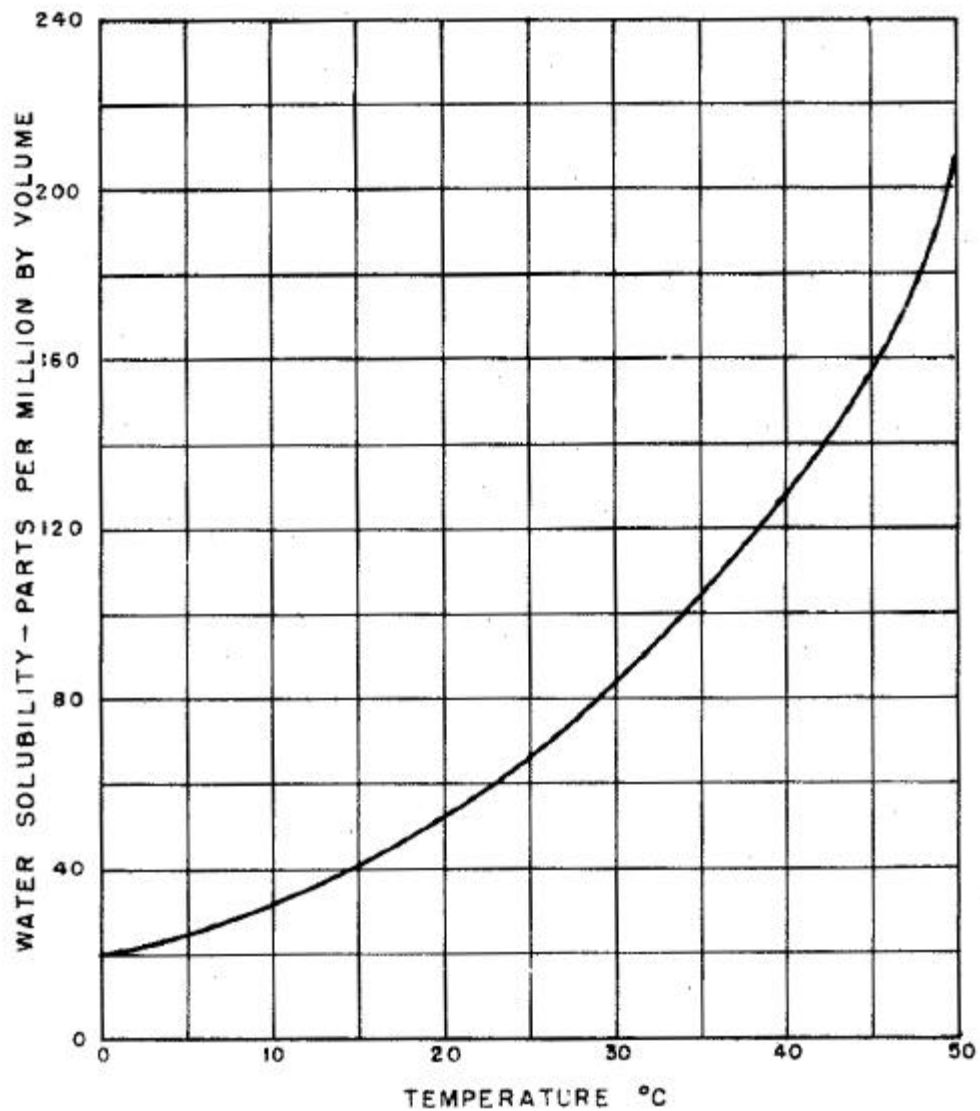
**2.3. OIL DETERIORATION IN TRANSFORMERS.-** In transformers, sludge sticks to surfaces through which heat should be dissipated; sludge forms a blanket barrier to flow of heat from the oil to the coolant and from the core and coils to cool oil. If allowed to continue long enough, sludge may even block off flow of oil through the cooling ducts. As a result, transformer insulation gets too hot and is damaged, particularly between turns of windings. Deterioration of turn insulation may eventually lead to short circuits between turns and the breakdown of the transformer. When oxidation progresses to the point where sludge is being precipitated, the first step should be to remove the sludge from the transformer by a high-pressure stream of oil and to either replace the sludged oil or treat it with activated clay to remove acid and sludge precursors. Complete treatment of the oil is normally less costly than replacing it with new oil. Methods of treatment are described later.



**Figure 1. - Relation between dielectric strength and amount of emulsified water in mineral oil. <sup>1</sup>**

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<sup>1</sup> From instruction book on insulating oil for electrical apparatus, Westinghouse Electric and Manufacturing Company No I.B 5336-D.



**Figure 2. - Maximum amount of water dissolved in mineral oil as affected by temperature.<sup>2</sup>**

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<sup>2</sup> From article in August 1940, Electrical Engineering, "Water Solution in High-Voltage Dielectric Liquids" by F. M. Clark, General Electric Company.

**2.3.1. Absorption of moisture by insulating materials.-** Solid insulation in transformers is very porous and absorbs much water. Some of the water dissolved in the oil is absorbed from the oil by insulation. As more water is dissolved in the oil, more water is absorbed by the insulation. Once the water is absorbed by the insulation, it is difficult to remove. The most effective method for drying out the insulation in transformers is with heat and vacuum. Sometimes a vacuum cannot be applied in the field; then the transformer insulation must be dried by circulation of hot, dry oil. This oil should then be cooled and dried. Since the dielectric strength of insulation is reduced by moisture, it is important that the insulation not be allowed to absorb moisture in the first place.

**2.3.2. Absorption of nitrogen by oil.-** Special precaution should be taken in operating nitrogen-blanketed transformers to avoid bubbling of the oil due to release of dissolved nitrogen when the pressure drops. Experience has shown that automatic gas-pressure regulating system should be adjusted to limit the nitrogen pressure range from plus 3.4.- to plus 21- kPa (plus 1/2- to plus 3-lb/in<sup>2</sup>) gauge to avoid formation of these bubbles and subsequent troubles due to corona deterioration.

**2.4. OIL DETERIORATION IN CIRCUIT BREAKERS.-** In circuit breakers, a spark flashes through the insulating oil during interruption. If oxygen is available in any form, water and carbon dioxide will be

formed first. When the oxygen supply runs out, carbon particles and hydrogen are formed. The hydrogen is dissipated as gas. Carbon particles can be seen visually. The presence of carbon particles generally spells trouble long before oxidative deterioration becomes significant.

### **3. TESTING OF INSULATING OIL**

**3.1. TYPES OF OIL TESTS.-** Four basic tests on insulating oil, when considered collectively, give a reasonably accurate diagnosis with respect to the serviceability of an insulating oil. The tests are (a) dielectric, (b) acidity, (c) power factor, and (d) IFT (interfacial tension). Other tests such as water content and oxidation inhibitor content may be required due to the operating environment and the equipment age.

**3.1.1. Dielectric test.-** The dielectric test measures the voltage at which the oil breaks down. The breakdown voltage is indicative of the amount of contaminant (usually moisture) in the oil, and the voltage should be checked frequently. The generally accepted minimum dielectric strength is 30 kV for transformers with an extra high-voltage rating 282 kV and above and 25 kV for transformers with a high-voltage rating below 282 kV. New oil should test at least 35 kV by ASTM methods of testing. Appendix B contains a discussion of field dielectric test equipment and methods. Oil is not necessarily in good condition even when the dielectric strength

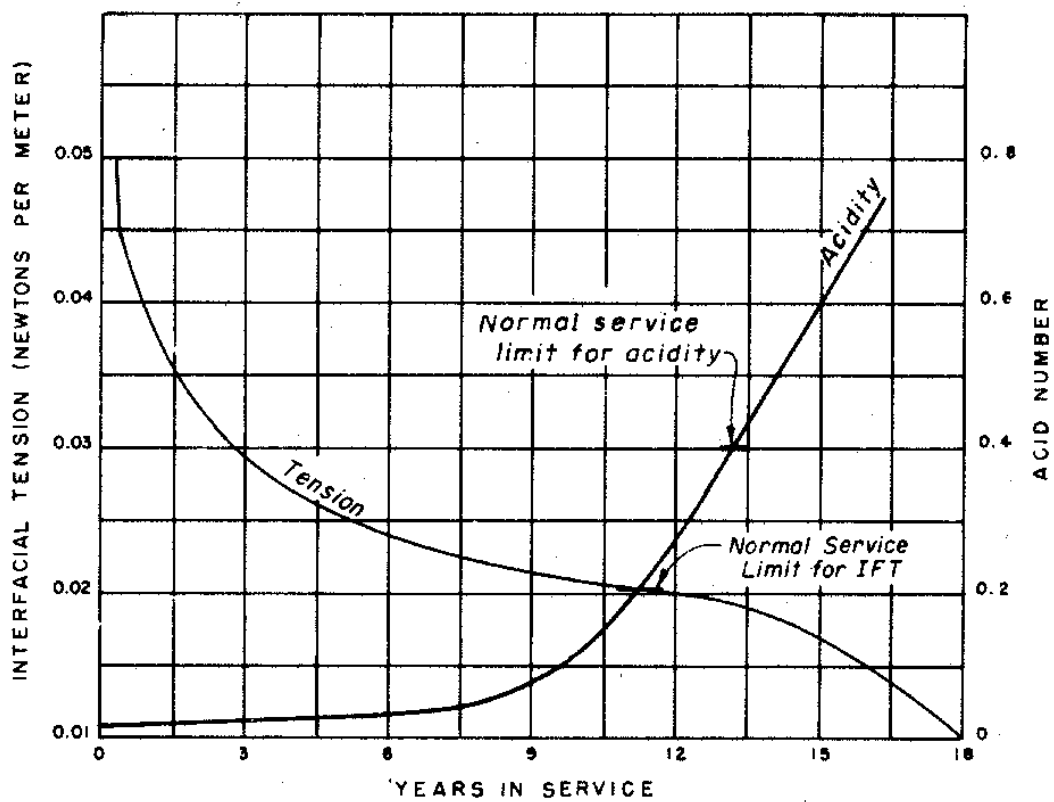


Figure 3. - Relation between service life, interfacial tension, and acidity in mineral oil.<sup>3</sup>

<sup>3</sup> Based on data from the AIEE Transactions, 1955, page 774

is adequate because this tells nothing about the presence of acids and sludge.

**3.1.2. Acidity test.**-New transformer oils contain practically no acids if properly refined. The acidity test measures content of acids formed by oxidation. Oxidation products polymerize to form sludge which then precipitates out. Acids react with metals on surfaces inside the tank and form metallic soaps, another form of sludge. Sludging has been found to begin when the acid number reaches or exceeds 0.4, and 0.4 is considered to be the normal service limit. New oil has an acid number of less than 0.05. The acid number (formerly referred to as neutralization number) equals the milligrams of KOH (potassium hydroxide) required to neutralize the acid contained in 1 gram of oil. It is questionable whether an oil that has deteriorated to the point where its acid number exceeds 0.6 can be put back into lasting good condition by a single renovation. It is almost certain that two or more renovations, spaced 6 months to 1 year apart, would be necessary. It is recommended that an upper limit of 0.2 be used to determine when oil should be renovated, as a single renovation would most probably restore such an oil to very good condition. Oil showing an acid number of 0.15 or larger can be expected to show accelerated acid formation ([fig. 3](#)). Appendix C contains a discussion of field acidity test equipment and methods. Tests have been made which indicate the acidity is proportional

to the amount of oxygen absorbed by the oil. It is estimated that 0.0015 m<sup>3</sup>/L (0.2 ft<sup>3</sup>/gal) of oxygen absorbed in oil will cause an acidity of about 0.4 mg of KOH, which is the approximate acidity number at which sludging is assumed to start. On this basis, equal loading test cycles and other assumptions, it has been estimated that different types of transformers would take the following periods of time before sludge would appear:

Transformers with free air access 10 years

Transformers with conservators 15 years

Transformers bolted tight 50 years

Transformers with nitrogen over oil 67 years

While the above periods may not correspond to actual field examples due to different load conditions than those assumed, they are illustrative of the relative periods of serviceability for different types of transformers.

**3.1.3. Power factor test.**- Power factor of an insulating oil equals the cosine of the phase angle between an ac voltage applied to an oil and the resulting current. Power factor indicates dielectric loss of an oil and, thus, its dielectric heating. The power factor test is widely used as an acceptance and preventive maintenance test for insulating oil. Oil power factor testing in the field is usually done with

the Doble type MH or M2H test set in conjunction with power factor tests of the oil-filled equipment. Test procedures for Doble instruments are given in appendix E. The power factor of new oil should not exceed 0.05 percent at 25 EC. A high power factor in used oil indicates deterioration or contamination or both with moisture, carbon, varnish, Glyptal, sodium soaps, or deterioration products. Used oil with a power factor in excess of 0.5 percent should be further analyzed in a laboratory to determine the cause of the high power factor. Oil with a power factor in excess of 2.0 percent may be an operational hazard. It should be investigated and either reconditioned or replaced.

**3.1.4. IFT test.**- It should be recognized that the acidity test alone determines conditions under which sludge may form but does not necessarily indicate that actual sludging conditions exist. The IFT (interfacial tension) test is employed as an indication of the sludging characteristics of power transformer insulating oil. It is a test of IFT of water against oil, which is different from surface tension in that the surface of the water is in contact with oil instead of air. Attraction between water molecules at the interface is influenced by presence of polar molecules in the oil in such a way that the presence of more polar compounds causes lower IFT. The test measures the concentration of polar molecules in suspension and

in solution in the oil and thus gives an accurate measurement of dissolved sludge precursors in the oil long before sludge is precipitated. It has been established that an IFT of less than 0.015 N/m (15 dyn/cm) almost invariably shows sludging. An IFT of 0.015 to 0.022 N/m (15 to 22 dyn/cm) shows an uncertain condition, and an IFT value of more than 0.022 N/m (22 dyn/cm) is generally indicative of no sludging. Transformer oils whose IFT is in the range of 0.015 to 0.022 N/m (15 to 22 dyn/cm) should be scheduled for reclaiming, regardless of acidity values. Appendix D contains a discussion of field IFT test equipment and methods.

**3.1.5 Water Content, ASTM D 1533** is especially important for EHV equipment. Manufacturers recommendations should be used for limits.

**3.1.6 Oxidation inhibitor, ASTM D 2668.** - Reclamation specifications require a DBPC content between 0.15 percent and 0.30 percent for new equipment. According to ASTM specification, oil with less than 0.08 percent DBPC is classified as non-inhibited oil. Therefore, when the level drops to less than 0.08 percent DBPC, inhibitor should be added to restore the level to approximately 0.30 percent DBPC. It is recommended that equipment 10 years or older be tested for oxidation inhibitor concentration when the physical tests are performed.

### **3.2. INTERPRETATION OF TEST RESULTS.**

- When results from all four tests are integrated, a sound conclusion can be drawn as to condition of the oil. Qualitative relationships exist between acidity and IFT (fig. 3) which are useful in interpreting test results. Note that the rate of change of IFT affords a more sensitive indication of early stages of deterioration. IFT measurements are particularly useful in judging the effectiveness of oil renovation processes, in identifying at an early stage new oil with poor life expectancy thus permitting helpful treatment while it is still practical, and to indicate when oil should be discarded and replaced. The rate of change of acidity often affords a more sensitive indication of deterioration near the sludge point. However, this is only true if the oil does not contain alkali impurities. Such impurities neutralize acids as they are formed, resulting in a low-acidity value.

### **3.3. PERIODIC TESTING PROGRAMS.-**

**3.3.1 Field test schedules.-** From the aspects of safety, continuity of service, and of efficient, low-cost maintenance, it is desirable to monitor condition of insulating oil by testing and to take remedial measures before the oil reaches a point of deterioration beyond which failure of equipment can be expected.

Condition of the oil and the load conditions should determine whether an annual, biannual, or more frequent schedule should be followed. Normally, acidity, IFT, power factor,

and dielectric tests should be made in major electrical equipment at least once a year. Permanent records should be kept of all test results. Whenever test results show accelerated deterioration, more frequent oil tests should be made to forestall trouble. For example, when the IFT reaches a value of 0.25 N/m (25 dyn/cm), more frequent testing is required to determine when the IFT value is approaching 0.022 N/m (22 dyn/cm) and the oil should be scheduled for reclaiming.

Idle, oil-filled equipment may also accumulate moisture and should be tested at least once a year. Cooling coils of water-cooled transformers sometimes develop leaks, and water may enter the oil so fast that even weekly dielectric tests would not catch the trouble. A rise in transformer oil level is the best indicator for this condition. Most water-cooled transformers are equipped with cooling tubes of double-wall construction. The intent of this construction is to bleed off leaking water or oil into space between the two walls of the tube to avoid contamination. Usually, oil pressure, and a double-wall leak causes oil to be lost into the cooling system discharge. The loss would be indicated by low oil level in the transformer. Hence, change of oil level is an important indication and should be checked frequently. Distribution transformers need not be tested as frequently as once a year, unless they are serving critically important loads such as the



main power station auxiliary motors and lights.

The presence of carbon in circuit breaker and step-voltage regulator oil introduces a hazard due to the tendency of carbon to lower dielectric strength of the oil and also to form deposits on insulating surfaces, reducing insulation resistance. Carbonized oil is more vulnerable to moisture than clean oil. The quantity of carbon is proportional to the number and severity of arcs interrupted. Samples of oil for dielectric test should be obtained from oil circuit breakers after a heavy fault or series of faults and from both types of equipment (circuit breakers and step-voltage regulators) at least twice a year. If an oil sample is black from suspended carbon, the oil should be filtered or centrifuged even though the dielectric test is good.

#### **4. RECONDITIONING USED INSULATING OIL**

**4.1. NATURAL PRECIPITATION.-** Oil that has low dielectric strength or contains deposits of sludge or other contamination should receive maintenance attention. Low dielectric strength indicates the need for drying by

mechanical filter or vacuum dehydrator. High acidity, high power factor, or low IFT values indicate the need for reclaiming treatment. When used insulating oils are to be subjected to reconditioning or reclaiming processes or both, every advantage possible should be taken of natural precipitation. Considerable savings can frequently be realized in processing used oil if it is allowed to remain in its container undisturbed for at least 24 hours so that water and suspended solids can settle out. The oil can then be removed without disturbing the residue in the bottom of the container; thus, it becomes unnecessary to remove this residue from the processing machinery.

**4.2. FILTER PRESSES.-**Filter presses vary somewhat in form but are based upon the principle of forcing oil under pressure through a series of absorbing and filtering materials, such as paper. Filters of this type are capable of removing carbon, free water, sludge, etc., when they are in suspension, but except for certain special arrangements, they cannot remove them effectively when they are dissolved or in colloidal form. These devices (particularly those with centrifuges) will not remove air but, in fact, tend to aerate the oil. Experience has shown that the most efficient temperature at which to

filter insulating oil is between 20 and 40EC (68 and 100EF). Below 20EC, the viscosity increases rapidly, while at temperatures above 40EC, the moisture is more difficult to separate from the oil.

#### **4.2.1. Filter press operation.**

When oil is to be purified by the use of a filter press using blotting paper, the paper should be well dried to obtain the most efficient operation; otherwise, the paper may actually add moisture to the oil. An oven should be used for drying the paper, and the sheets should be separated as they are hung on rods in the oven to permit free circulation of air and to ensure the most rapid drying. The filter paper should be dried from 6 to 12 hours at a temperature of 101 to 105EC (214 to 220EF). After drying, the paper should be taken from the oven directly to the filter, or it may be stored in dry transformer oil for future use. When transferring the paper, care should be taken to handle it as little as possible to avoid the absorption of moisture from the hands and to minimize the time of exposure to the air.

When purifying oil containing materials such as sludge or small carbon particles, considerable back pressure will develop as the filtering progresses because of the materials clogging up the filter paper. When the back pressure reaches about 517 kPa (75 lb/in<sup>2</sup>), the paper should be replaced. When cleaning circuit breaker oil

containing a large amount of free carbon, the accumulation of sediment on the surface of the paper makes frequent replacement of paper necessary. In such cases, it is more economical to remove only the sheet of paper nearest the oil inlet frame in each section (the solid matter collects there) and insert the replacement sheet at the discharge end of the stack.

When purifying very wet oil with a filter press, the back pressure will not increase appreciably as the filter paper absorbs moisture. Therefore, the operator should make frequent dielectric tests of the oil discharged from the filter press to determine when the paper should be replaced.

**4.3. CARTRIDGE FILTERS.-** In recent years, many Reclamation projects have purchased mobile cartridge-type filters for reconditioning transformer and circuit breaker oil. The most popular of these units are the AMF "Cuno-Pore" and the Alsop "Hy-Speed" filters. These units are available in various sizes with oil-processing capacities ranging from 37.8 to 284 L/min (10 to 75 gal/min) and utilize disposable cartridges with filter densities ranging from 1 to 25 micrometers. (Note: The 6-micrometer filters are recommended for transformer oil; and 6- to 1-micrometer filters for circuit breaker oil.) These mobile filter units are smaller, lighter, and more portable than large filter presses, have greater oil-flow capacities, and in most cases, provide better water and particle

removal. In addition, no drying oven is required since the filter cartridges are hermetically sealed in plastic for shipment and storage.

**4.4. CENTRIFUGES.-** Another means of separating free and suspended contaminants, such as carbon, water, sludge, etc., from oil is the continuous centrifuge. In general, the centrifuge can handle much greater concentrations than can the conventional filter press, but it cannot remove some contaminants as completely as a filter press. Consequently, the centrifuge is generally used for rough-bulk cleaning where large amounts of contaminated oil are to be handled. Frequently, output of the centrifuge is put through a filter press for final purifying. The centrifuge cannot remove dissolved water from oil since the centrifuge is sealed with water, the oil leaving the centrifuge may be saturated at the temperature of operation and conceivably could contain more dissolved water than when it entered. Neither the centrifuge nor the filter press is designed to treat oil chemically.

**4.5. COALESCERS.-** Coalescers are used to remove free water from both lubricating and insulating oils. Coalescing filtration is a relatively new technique that has been borrowed from the aviation fueling field. Fiberglass cartridges trap small water particles; increasing differential pressure across the filter media forces the particles of water together, and the large water drops are extruded at the outer surface of the fiberglass element. Large water drops are retained within a water-repellent

separator screen and collect, by gravity, at the bottom of the filter while dry oil passes through the separator screen. This method is quite similar to centrifuging with respect to performance and limitations. Coalescing filters have no moving parts, and therefore, are simpler in operation and maintenance than centrifuges; however, any particulate matter in the oil will clog a coalescer and render it useless.

**4.6. VACUUM DEHYDRATORS.-** The vacuum dehydrator is efficient in reducing water content of an insulating oil to a very low value. In this apparatus, oil is exposed to a vacuum and heat for a short interval of time. Vacuum dehydrators can be used to treat oil without removing associated equipment from service. In addition to removing water, vacuum dehydrators will degas oil and remove more volatile acids. Vacuum dehydrators are frequently used by the manufacturer during initial filling of new transformers.

**4.7. ELECTROSTATIC OIL FILTER.-** A lightweight, portable, electrostatic oil filter is marketed by Electro Filter Systems, Division of International Plasma, Inc., Hayward, California. The Electro-Filter has been demonstrated to O&M personnel in several regions; it removes water, particulates, and polar contaminants from insulating oil by a unique nonionizing electrostatic filtration method. The manufacturer states that the unit is capable of dehydrating oil to a level below 10-ppm absolute, and that it removes salt and submicroscopic particulates without affecting

concentration of additives in the oil. For oil containing a substantial quantity of free water, a coalescing filter should be used upstream of the Electro-Filter. A combination of these units is claimed to achieve an oil dielectric strength in excess of 40 kV in a single pass. The unit operates on 110 or 220 V ac. An electrostatic power supply provides 12 mA at plus and minus 5 kV dc to a series of alternating positive and negative grids. Particles are entrapped within the filter in three distinct ways: (1) electrostatic attraction and containment of particles to the grid elements, (2) mechanical bonding (impaction) of particles to the grid elements, and (3) entrapment of contaminants between grid elements. When contaminated, the grids are removed as a unit, rinsed in solvent, and reinstalled.

#### **4.8. TREATMENT OF CIRCUIT BREAKER**

**OIL.-** Although it is customary to recondition circuit breaker oil in much the same manner as transformer oil, the problem is somewhat different. Whereas sludging is, or may be, the principal problem in transformer oil, this is not the case with circuit breaker oil. Conditions conducive to sludge formation and other deleterious effects produced in transformers, do not normally occur in circuit breakers. Aside from being dielectric, the chief function of transformer oil is to dissipate heat; however, in a circuit breaker it is to quench the arc. In so doing, chemical breakdown can occur and minute particles of carbon form which impair the dielectric strength of the oil. If present in sufficient quantity, these particles are deposited onto insulating members until a

short circuit results. Testing methods for circuit breaker oils are the same as those used for transformer oils. The chief problem in circuit breaker oil maintenance is to keep oil free of water, conducting products, and other contaminants. A filter press or cartridge filter is the accepted method of reconditioning; however, the normal filter press paper is not dense enough to remove all the colloidal contaminants in the oil. The method used to remove colloidal and other contaminants completely is to introduce a small amount of activated clay into blotter press interstices. This is accomplished very simply by mixing a small amount of clay 25 to 50 mL in 8 to 12 L (1 to 2 cups, in a few gallons) of oil and then passing the mixture through the filter press prior to the main filtering operation. The clay is removed from the oil and deposited on the filter papers, thus producing, in effect, a much denser filtering medium. No reduction in acidity of the oil is to be expected, since the amount of clay used is very small.

##### **4.8.1. Changing oil in oil-poor circuit breakers.-**

Presence of carbon in oil increases susceptibility of the oil to deterioration due to moisture, thereby increasing the rate at which oil loses dielectric strength. For certain oil-poor circuit breakers, the carbonizing effects are severe and frequent treatment is required, it is more practical to replace the oil than try to filter it since the quantity of oil thus lost is relatively small.

#### **4.9. TREATMENT OF OIL IN TAP CHANGERS.-**

Oil used in load tap

changing compartments or in step-voltage regulators is usually the same type as that used in transformers. Maintenance of this oil is fundamentally the same as in circuit breakers. However, there is a contaminant sometimes present in oil exposed to this type of service that does not exist to any great extent in circuit breaker oil. The large number of operations of contacts in this type of device is quite likely to produce a considerable amount of very fine copper dust. This can be removed in the same manner as previously stated for circuit breaker oils; however, precautions should be taken if the presence of these fine copper particles in the oil will harm reconditioning equipment. Rotary pumps with close clearances can be seriously damaged if copper particles are allowed to pass through them. Also, copper is an oxidation catalyst which increases the rate of oil deterioration. Due to this oxidizing characteristic and the difficulty involved in removing these copper particles prior to entrance into the pump, it is usually desirable to dispose of the contaminated oil and replace it with new oil.

#### **4.10. IN-SERVICE OIL FILTERING.-**

One Reclamation facility and several electric utilities have successfully utilized in-service, oil-filtering systems on transformer tap changers and oil circuit breakers used for capacitor and reactor switching. In-service filtering is reported to remove much of the carbon and copper particles from the oil and thus greatly extend the interval for oil reconditioning and equipment

maintenance. A typical installation consists of a permanently mounted pump of 11.4-L/min (3 gal/min) capacity and a truck-type oil filter of 19-L (20-qt) capacity using 2-micrometer filter elements. Daily filtering periods may be controlled with a time switch or be interconnected with the switching operation.

#### **4.11. LIMITED INTERCHANGEABILITY OF OILS.-**

Oils should not be retired from a circuit breaker and put to use in a transformer. The primary reason is the difficulty involved in removing arc and oxidation products while maintaining resistance to sludging. On the other hand, oil used in a transformer can be transferred to a breaker; in which case, the oil should pass tests for circuit breaker oil, as previously outlined.

#### **4.12. DISPOSAL OF OIL.-**

It is recommended that more insulating oil which is excess is no longer suitable for use in electrical apparatus be tested for PCB contamination prior to disposal. EPA regulations do not require that this test be performed, they state that dielectric fluid must be assumed to be PCB contaminated if the test is not performed and the EPA disposal regulations listed in [section 10.4](#) would then apply to it. Other uses can be made of oil which is no longer suitable for use in electrical apparatus and contains no detectable PCB's. These uses include mineral oil in oil-burning heaters and in weed and dust control. Care should be taken to avoid contamination of water supplies or creation of fire hazards when oil is disposed of.

## 5. RECLAIMING USED INSULATING OIL

### 5.1. FULLER'S EARTH METHOD. -

Fuller's earth is the material most frequently used for reclaiming oils. Fuller's earth is a natural clay mined near Attapulcus, Ga., and Ocala, Fla. Chemically it is crystalline hydrated magnesium aluminum silicate, with a unique chain structure which gives it unusual colloidal and absorptive properties. The most common reclaiming method is by gravity or pressure percolation of oil through 300-180 micrometer or 212-163 sieve (50-80 or 70-90 mesh) Fuller's earth at a rate of 0.06 to 0.12 kg/L (1/2 to 1 lb/gal) of earth per oil with associated mechanical filtration and vacuum dehydration equipment.

#### 5.1.1 Portable, oil reclaiming

**units.-** At the present time, Reclamation has a portable Bowser (Keene Corp.) unit located at Grand Coulee Dam. This unit is designed to process oil at a rate of about 2,270 L/h (600 gal/h) and utilizes bulk Fuller's earth in dual tank is of 68-kg (150-lb) capacity each. This unit is equipped with an oil heater, utilizes "Cuno-Pore" (AMF, Inc.) cartridge filters, employs a high-vacuum system for removing moisture and gas, and provides a method of introducing DBPC into the processed oil. This unit may be used to reclaim oil in energized transformers and when so used, the flushing action removes carbon and sludge deposits from the transformer coils, core, radiators, and tank. Portable instruments for measuring dielectric strength,

power factor, IFT, and moisture content are used to determine the optimum end point for the reclaiming process.

### 5.2. ACTIVATED ALUMINA METHOD.-

Activated alumina has been successfully used by several electric utilities and at least one Reclamation facility in recent years for in-service transformer drying. This process is relatively simple and economical, although it requires considerably more time than the vacuum dehydrators described above. The process involves continuous forced circulation of oil from the top of the transformer through a tank of activated alumina and back into the bottom of the transformer over a prolonged period of time (3 to 6 months or longer). The activated alumina absorbs water from the oil on contact, and the relatively dry oil then extracts moisture from the core and coil insulation. At the same time, acids, polar contaminants, and particulate matter, such as colloidal carbon, are removed from the oil. A typical drier system consists of a steel tank about 0.9 m (3 ft) high and 0.6 m (2 ft) in diameter holding approximately 227 kg (500 lb) of grade F-3, 2.36-1.40-mm sieve (8-14 mesh) activated alumina, an oil pump with a flow rate of 3.8 to 19 L/min (1 to 5 gal/min), and associated valves and piping. A check valve is installed at the bottom transformer connection to prevent draining the transformer in the event of a leak in the drier system. A silica-gel breather is installed on free-breathing, conservator-type transformers to prevent additional

moisture from entering the transformer. The activated alumina charge is changed every 2 to 3 months.

## **6. OXIDATION INHIBITORS FOR INSULATING OIL**

**6.1. NATURAL INHIBITORS.-** New insulating oil as normally refined contains small amounts of certain chemical compounds that act as oxidation inhibitors. These naturally occurring materials retard oil oxidation until such time as they are expended. The rate at which the inhibitors in oil are used up is dependent upon the amount of oxygen available, soluble contaminants in the oil, catalytic agents in the oil, and the temperature of the oil. In modern transformers, either sealed to exclude air and moisture or protected by an inert atmosphere, the benefits of the inhibitors can be extended over many years. As the inhibitors are exhausted, the rate of oxidation and the deterioration of the oil increases. Reclaiming processes, such as acid refining or clay treating, can restore oil so that it has most of its original characteristics, but this has no effect upon restoring the usefulness of the natural inhibitors occurring in the oil. In fact, both Fuller's earth and activated alumina remove the natural inhibitors and the reclaimed oil has no resistance to oxidation. To overcome this undesirable condition, synthetic oxidation inhibitors should be used to extend the life of the reclaimed oil.

**6.2. INHIBITOR ACTION.-** A number

of organic chemical compounds are known to slow down the oxidation when added to lubricating or insulating oils. Such additives are known as antioxidants or oxidation inhibitors. Unfortunately, all known oxidation inhibitors become depleted with time. When all of the inhibitor has been used up, the oil starts to deteriorate again, and deterioration proceeds in the same way at the same (or greater) rate as in an uninhibited oil. The useful life of the oil is extended by the amount of time the inhibitor remains effective, before it becomes depleted, usually a few years.

**6.3. THE DBPC INHIBITOR.-** An inhibitor material that has found almost universal approval is known, chemically, as 2,6-ditertiary-butyl para-cresol, but is generally referred to as DBPC. This material is a very desirable inhibitor and has outstanding properties which, even in small concentrations, is a stable and effective oil antioxidant. Since the natural inhibitors are consumed by oil in service and are completely removed by Fuller's earth; it is important that, following the reclaiming process, an inhibitor, such as DBPC, be added to the oil. Reclaimed oil should be tested for DBPC content, DBPC is commercially available in a concentrated oil solution or in dry-flake form which must be dissolved in hot transformer oil before using. A concentration of 0.3 percent DBPC by weight is recommended (table 2). Since DBPC is nonpolar and insoluble in water, it is not removed from the oil by Fuller's earth treatment if the temperature is kept below 75 EC (167 EF).

**Table 2. - Effective DBPC antioxidant concentration of IMPRUVOL 20 (Koppers Co.)**

Percent DBPC antioxidant by mass desired in transformer oil	Kilograms DBPC antioxidant per 1000 liters transformer oil <sup>1</sup>	Pounds DBPC antioxidant per 100 gallons transformer oil <sup>1</sup>	Liters IMPRUVOL 20 per 1000 liters transformer oil <sup>2</sup>	Gallons IMPRUVOL 20 per 100 gallons transformer oil <sup>2</sup>
0.1	0.9	0.7	5.0	0.5
0.2	1.8	1.5	10.0	1.0
0.3	2.6	2.2	15.0	1.5
0.4	3.5	3.0	20.0	2.0
0.6	5.3	4.4	30.0	3.0
0.8	7.0	5.9	40.9	4.0

<sup>1</sup> Density of typical transformer oil - 876 kg/m<sup>3</sup> (7.31 lb/gal).

<sup>2</sup> Density of IMPRUVOL 20 - 896 kg/m<sup>3</sup> (748 lb/gal).

**6.3.1. Sample problems.-** A transformer contains 800 L (211 gal) of oil. It is desired to inhibit the oil in the transformer with 0.3 percent by weight DBPC antioxidant.

**6.3.1.1 To use IMPRUVOL-20.** - The addition of 0.3 percent by mass of DBPC antioxidant (table 2) to transformer oil corresponds to 15 L IMPRUVOL-20 per 1,000 L (1.5 gal IMPRUVOL-20 per 100 gal) of transformer oil. Since the transformer contains 800 L (211 gal) of oil, multiply 15 L by 0.8 (1.5gal by 2.11) which gives 12 L (3.17 gal) of IMPRUVOL-20 necessary to provide 0.3 percent DBPC antioxidant concentration in the transformer.

**6.3.1.2. To use flake DBPC antioxidant.-** To compute the amount of flake DBPC antioxidant needed, take

2.6 kg DBPC antioxidant per 1,000 L (2.2-1b DBPC antioxidant per 100 gal) transformer oil, from table 2, which corresponds to a level of 0.3 percent DBPC antioxidant inhibition. Multiply this figure by 800 L/1,000 L (211 gal/100 gal). The result is 2.08 kg (4.64 lb) DBPC antioxidant for the transformer.

The volume of transformer oil required to prepare a 20 percent by mass DBPC antioxidant oil solution for adding 2.10 kg (4.64 lb) of DBPC antioxidant to the transformer is obtained by multiplying the figure 2.10 kg (4.64 lb) by the factor 4.57 L/kg (0.55 gal/lb) to give 9.6 L (2.55 gal). If the mass of transformer oil for preparing this solution is required, multiply 2.10 kg (4.64 lb) DBPC antioxidant by the factor 4 to give 8.42 kg (18.6 lb) of oil.



## **7. TESTING FOR GASES IN POWER TRANSFORMERS AND REGULATORS**

The chemical decomposition of materials within transformers generates combustible gases. Degradation by excessive heating or electrical discharges is very common. Severity of gassing depends on the nature of the problem, which can range from low-level corona or overheating to total insulating failure. The combustible gas test has proven to be a particularly valuable means of detecting overheating or incipient low-energy faults in transformers and regulators since such problems normally cannot be detected by electrical tests. Early detection of problems is particularly important because it allows time for planned corrective action to be taken and, therefore, minimizes chances of damage to the units and emergency outages. Reclamation presently uses two methods of testing for combustible gases. These are combustible gas analyzers and gas-in-oil analysis by gas chromatography.

**7.1. COMBUSTIBLE GAS ANALYZERS.-** Most Reclamation regions have acquired and used combustible gas analyzers to test periodically for an indication of internal conditions in power transformers and regulators with a nitrogen seal or constant pressure system. In several oases, incipient problems have been detected and corrective action has been taken in an economical and timely manner. This section gives guidelines for Reclamation-wide use of this valuable technique as a periodic maintenance

tool. It has been established that electrical problems in transformers are invariably accompanied by the generation of a variety of combustible gases as a result of the local decomposition of the surrounding insulated materials.

To utilize gas generation as an indicator of incipient malfunction, the detector should be specifically designed for combustible gas detection. Quantitative tests can be satisfactorily made using either the Pennsylvania Transformer Company portable gas detector or the Johnson Williams combustible gas indicator. Where continuous combustible gas monitoring is necessary and justified, the McGraw-Edison "Fault Gas Recorder" has the capability of performing this type of service. The recommended program for the performance of quantitative testing for combustible gas is shown ([table 3](#)) for power transformers and regulators with nitrogen seal or constant pressure system.

A new transformer or regulator should be tested within a week after energization. If it is not gassing and does not start gassing, subsequent tests should be made at progressively increasing intervals until the 12-month normal interval is reached.

To facilitate the combustible gas testing program, all equipment having constant pressure systems should have a gas sampling line installed from its gas accumulation relay to a ground-level sampling valve. All equipment having a nitrogen blanket should have a gas

**Table 3. - Quantitative testing for combustible gas**

Percent combustible gas	Evaluation
0 -1	<p>Check each transformer or regulator every 12 months. After three successive to 1 percent range tests, the testing interval may be expanded to 2 years. Equipment shows some indication of contamination or slight incipient fault. Take readings at 3- to 6-month intervals to establish a trend</p> <p>Take readings at monthly intervals. If trend continues upward, prepare to investigate cause, preferably by internal inspection. Gas samples should be taken (A-4) and sent to the Denver Office for quantitative and qualitative analysis on the gas chromatograph which may reveal the cause of gassing. Remove equipment from service as soon as possible. Investigate by internal inspection. Prepare to move equipment to service shop.</p>
1-2	
2 - 5	
Greater than 5	

sampling line installed from the upper portion of the tank to a ground-level sampling valve.

**7.2. GAS-IN-OIL ANALYSIS.** - Reclamation has been conducting gas-in-oil analysis of insulating oils by gas chromatography and has had excellent results with this testing program. The gas-in-oil analysis is more sensitive than the combustible gas analyzer and can detect transformer problems earlier because of the following:

- a. The combustibles are all very soluble in oil, and there is little tendency for them to migrate into the gas space if the concentration is low.
- b. Normal oil circulation dilutes gases as they are formed and there is no appreciable release into the gas blanket until the gases accumulate in the whole body of the oil.

c. Certain important gases (for example, acetylene) exhibit such high affinities for oil that they are not easily released with the result that analysis of free gas from transformers may be quite misleading in terms of the actual decomposition products.

As the gas-in-oil analysis test procedure has proven to be predictive and valuable, it is recommended that annual gas-in-oil analysis tests be performed on Reclamation transformers containing insulating oil. Normally the oil samples may be sent to a commercial oil testing facility. Appendix F contains diagnostic criteria for gas-in-oil analyses of transformer insulating oil. Further information or discussion regarding interpretation of gas-in-oil analysis can be obtained from the Denver Office, Attention D-8450.

## PART II - ASKARELS

### 8. CHARACTERISTICS OF ASKAREL

#### 8.1. LIQUID ASKAREL

**CHARACTERISTICS.**- Askarel is the term used to describe a broad class of nonflammable, synthetic, chlorinated, hydrocarbon insulating liquids used in electrical equipment. Askarel is composed of PCB's (polychlorinated biphenyls). Monsanto Industrial Chemical Company was the only United States corporation making as-karel. Monsanto mixed Aroclor (a Monsanto trademark), a PCB, with chlorobenzenes to produce different blends for electrical manufacturers.

Some common electrical manufacturer trade names for askarel blends are listed in table 4. On newer askarel filled transformers and capacitor cans, these trade names will be marked on the nameplate.

Some general characteristics of askarel are:

1. Heavier than water.
2. Higher dielectric strength than mineral oil.
3. Nonflammable.
4. Nonexplosive.
5. Not susceptible to deterioration by oxidation.
6. Lower coefficient of expansion than mineral oil.
7. Will dissolve some insulating materials and paints.
8. At ordinary operating temperatures, the viscosity of askarel is

**Table 4.** - *Manufacturers' names used for PCB's*

Askarel <sup>1</sup> trade name	Equipment manufacturer
Aroclor	Monsanto
Asbestol	American Corp.
Chlorextol	Allis Chalmers
Diaclor	Sangamo Electric
Dykanol	Cornell Dubilier
Elemex	McGraw Edison
Hyvol	Aerovox
Inerteen	Westinghouse Electric
No-Flamol	Wagner Electric
Pyronol	General Electric
Saf-T-Kuhl	Kuhlman Electric
Clophen	Bayer (Germany)
DK	Caffaro (Italy)
Fenclor	Caffaro (Italy)
Kennechlor	Mitsubishi (Japan)
Phenoclor	Prodelec (France)
Pyralene	Prodelec (France)
Santotherm	Mitsubishi (Japan)

<sup>1</sup>Generic name used for insulating liquids in capacitors and transformers, which contains approximately 50 percent PCB's.

approximately the same as that of insulating oil.

9. As is the case with insulating oils, the dielectric strength of as-karels is reduced by the presence of moisture.

#### 8.2. DESIGN OF ASKAREL-FILLED TRANSFORMERS.

- Transformers in which askarel is used differ in design from the conventional oil-filled transformers. Special insulating material that will not be attacked by askarel must be used. As askarel has a higher dielectric strength

than mineral oil, the distances between live parts can be decreased. Because of the higher cost of askarel, the transformers were sometimes designed to give high efficiencies which increased the copper and steel cost, but decreased the amount of cooling liquid required. The lower askarel coefficient of expansion made it possible to hermetically seal larger transformers that could not have been sealed if oil filled. Askarel should never be used in a transformer designed for mineral oil, and mineral oil should not be used in a transformer designed for askarel without first consulting the manufacturer. The larger-sized askarel-filled transformers usually have a relief diaphragm which is protected during shipment by a pipe plug or a blind flange. This plug or blind flange should be removed before the transformer is put in service, and periodic inspections should be made to see that the diaphragm has not been broken.

## **9. MAINTENANCE OF ASKARELS**

EPA (Environmental Protection Agency) rules and regulations for PCB's published in the Federal Register on May 31, 1979, now regulate the servicing of PCB transformers. The rules permit routine servicing of PCB transformers but prohibit rebuilding them. Routine servicing is defined to include testing the dielectric fluid, filtering the fluid, and replacing gaskets.

**9.1. INSPECTION.-** Standard maintenance practices for askarel included visual inspection and dielectric strength tests when the equipment was initially installed,

and on a regular schedule at 3-year intervals there after. Visual inspection that reveals a clear, faint yellow, or light brown color indicates good askarel condition. The presence of a green, red, or blue cast, cloudiness, or turbidity indicates the presence of insulation or moisture contamination and further tests on the askarel and inspection of the associated equipment should definitely be made. If the askarel sample appears black or contains suspended carbon particles, severe arcing has occurred and a thorough inspection of the equipment should be performed. Due to the present environmental problems associated with handling askarel, we presently recommend that the transformer fluid not be routinely inspected.

**9.2. SAMPLING.-** Samples of askarel should be taken in a 0.001 m<sup>3</sup> (0.26 gal) stainless steel cylinder similar to those used for oil samples. When the sample is to be sent to the Denver Office, indicate the temperature of the askarel when the sample was taken. Samples of askarel should be taken when the relative humidity of the environment is low and when the temperature of the askarel when the sample was taken. Samples of askarel should be taken when the relative humidity of the environment is low and when the temperature of the askarel is as high or higher than the surrounding air. It is best to take the sample when the unit is near operating or maximum temperature. Samples taken during regularly scheduled intervals should be taken at nearly the same temperature as previous samples. Samples should be taken as close to the top of the liquid surface as possible because askarel is

heavier than water. Due to the environmental problems involved with the handling of askarel, routine sampling should be discontinued.

**9.3. TESTING.**- The testing procedure for askarel is the same as for mineral oil, but care should be taken to see that there is no mineral oil in the test cup. The dielectric strength test for askarel is the most important maintenance test. A high-dielectric strength indicates that the insulating efficiency of the askarel is high and that any cloudiness or turbidity present is not due to damaging moisture contamination. If the dielectric strength of the askarel decreases abruptly or a decreasing trend is observed, inspections should be made at more frequent intervals. A high-power factor alone is insufficient criterion for replacing or reconditioning askarel; however, where abnormally low values of dielectric strength occur, the power factor of the askarel can be expected to be abnormally high. Power factors of 20 percent and more are frequently encountered in askarel transformers during normal service. Although this is an indication that some contamination has occurred, experience has shown that askarel is serviceable long after power factor test values increase greatly. Again, the determining criterion which indicates the serviceability of askarel is the dielectric strength. Reconditioning askarel to obtain a lower power factor is usually not justified.

**9.4. CONTAMINATION.**- Water contamination is the primary cause of deterioration of askarel dielectric strength. Inspect all askarel-filled equipment for possible areas that would allow the equipment to "breathe" moisture-laden air. Numerous sealing compounds are available for sealing these areas. Where gaskets are located, use Silastic seals at the flanges, Viton for an elastomeric seal, and Teflon tape on pipe threads. On older equipment, cork-type gaskets should have the outside edges sealed with epoxy cement.

**9.5. RECONDITIONING USED ASKAREL.**- The fact that the transformer tanks are generally sealed and that any condensation will float on top of askarel makes filtering by a blotter press rarely necessary. If such filtering is necessary, it can be done with an ordinary press.

Askarel should not be filtered in equipment that is also used for filtering insulating oils, due to the possibility of contaminating the insulating oil with PCB's. Even slight contamination (less than 50 mg/L (p/m)) of "clean oil" will necessitate special treatment of the oil and may ultimately prove very costly.

A centrifugal purifier designed for mineral oil will not function on askarel. Special combination activated clay purifiers and blotter presses are manufactured for askarel, and one

such unit is presently used at Grand Coulee Dam. See [section 10.4](#) for disposal requirements for clay, blotter paper, rags, clothing, etc., which have been contaminated by PCB's.

## **10. HANDLING AND DISPOSAL OF ASKAREL**

**10.1. SAFETY PRECAUTIONS.-** Askarel has been made and handled for over 60 years, and the potential health hazard from PCB's was not recognized until recently. The Department of Health, Education, and Welfare has identified PCB's as "cancer suspect agents" based on animal experimentation, although there have been no toxic effects documented from human exposure. The recommended TLV (threshold limit value) of 1.0 g/m<sup>3</sup> for airborne concentrations is designed to protect the health and provide for the safety of employees up to a 10-hour workday, 40-hour work week, over a normal working lifetime. Additionally, as with many organic chemical solvents, skin irritations may occur as a result of prolonged exposure, and the following precautions are to be followed when handling askarel:

1. Skin contact is to be avoided. Utilize neoprene gloves, sleeve guards, aprons, neoprene boots, eye goggles, or face shield.
2. Heating of askarel is prohibited unless the system is entirely enclosed and vapor contact is controlled so there is no exposure to workmen.

### **First Aid:**

1. Skin contact. Wash area contacted with soap and water as soon as possible.
2. Eye contact. Flush eye with water for 15 minutes and consult a physician. Note: Take askarel label or product information along to the physician.
3. Respiratory contact. Remove to a fresh air supply and notify a physician.
4. Clothing contact. Remove and wash, dry, clean, or discard.

Ingestion or swallowing of askarels is not likely and therefore is not generally regarded as a problem of the industry. Should accidental ingestion occur, a physician should be consulted. Hands should be washed with warm water and soap before eating, drinking, smoking, or using toilet facilities.

### **10.2. RECORDS AND MONITORING.-**

Records on the disposition of PCB's and PCB items are required by the EPA for each facility sing or storing at one time at least 45 kg (99.4 lb) of PCB's contained in PCB containers or one or more PCB transformers, or 50 or more PCB large high- or low-voltage capacitors. These records shall form the basis for an annual document prepared for each facility by July 1 covering the previous calendar year. Projects with one or more facilities that use or store PCB's and PCB items in the quantities described above may maintain the records and documents

at a facility that is normally occupied for 8 hours a day, provided the identity of this facility is available at each facility using or storing PCB's and PCB items. The records and documents shall be maintained for at least 5 years after the facility ceases using or storing PCB's and PCB items. The following information for each facility shall be included in the annual document.

**10.2.1.** The dates when PCB's and PCB items are removed from service, are placed into storage for disposal, and are placed into transport for disposal. The quantities of the PCB's and PCB items shall be indicated using the following breakdown:

**10.2.1.1** Total weight in kilograms of any PCB's and PCB items in PCB containers, including the identification of container contents, such as liquids and capacitors.

**10.2.1.2.** Total number of PCB transformers and total weight in kilograms of any PCB's contained in the transformers.

**10.2.1.3.** Total number of PCB large (greater than 1.360kg (3-lb) dielectric fluid) high- or low-voltage capacitors.

**10.2.2.** For PCB's and PCB items removed from service, the location of the initial disposal or storage facility and the name of the owner or operator of the facility.

**10.2.3.** Total quantities of PCB's and PCB items remaining in service at the end of the calendar year using the following breakdown:

**10.2.3.1.** Total weight in kilograms of any PCB's and PCB items in PCB containers.

**10.2.3.2.** Total number of PCB transformers and total weight in kilograms of any PCB's contained in the transformers.

**10.2.3.3.** Total number of PCB large high- or low-voltage capacitors.

### **10.3. MARKING OF PCB'S AND PCB ITEMS.-**

Each of the following items shall be marked ([fig. 4](#)) unless the PCB item is too small to accommodate the smallest permissible size of the mark which is 152 mm (6 in) on each side. If the equipment is too small for this mark, the small mark ([fig. 5](#)) may be used. The small mark which is 25 by 50 mm (1 by 2 in) may be reduced to a minimum of 10 by 20 mm (0.4 by 0.8 in for small items).

**10.3.1.** PCB containers.

**10.3.2.** PCB transformers.

**10.3.3.** PCB large high-voltage capacitors.

**10.3.4.** Equipment contained a PCB transformer or a PCB large high-voltage capacitor.

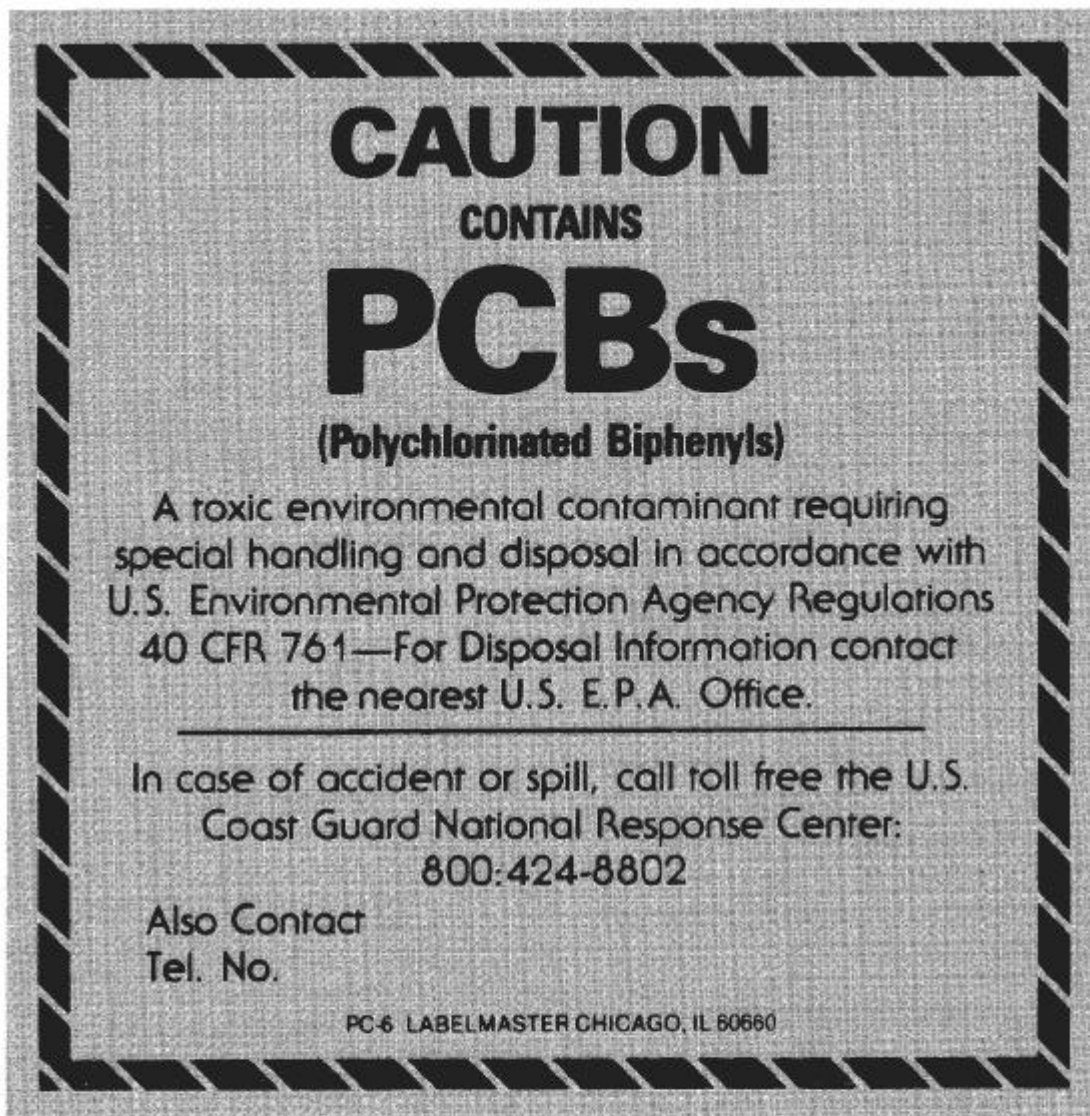


Figure 4. - Standard PCB Mark.



Figure 5. - Small PCB Mark.



**10.3.5.** PCB large low-voltage capacitors.

**10.3.6.** Electric motors using PCB coolants.

**10.3.7.** Hydraulic systems using PCB hydraulic fluid.

**10.3.8.** Heat transfer system (other than PCB transformers) using PCB's.

**10.3.9.** PCB article containers containing articles or equipment that must be marked under the provisions above.

**10.3.10.** Each storage area used to store PCB's and PCB items for disposal.

**10.3.11.** Each transport vehicle shall be marked on each end and side if it is loaded with PCB containers that contain more than 45 kg (99 lb) of PCB's in the liquid phase or with one or more PCB transformers.

#### **10.4. DISPOSAL PROCEDURES AND SERVICES.-**

**10.4.1. Environmental pollution.** - During the past 40 years of use, PCB's have been widely dispersed throughout the environment. PCB's are only compounded and do not occur in nature. In the past several years, evidence has shown that PCB's can have adverse environmental and toxicological effects. PCB's, like arsenic and mercury, are subject to bioaccumulation which is

the process by which living organisms concentrate an element or compound to levels that are harmful to living organisms. Because of their adverse physiological effects to living organisms and because of their tendency toward bioaccumulation, PCB's have been declared a hazardous waste. Final regulations prescribing the disposal, storage, and marking requirements for PCB's were published in the Federal Register, May 31, 1979. These regulations implemented provisions of the Toxic Substances Control Act (Public Law 94-469) and became effective on July 2, 1979. The regulations apply to all persons who manufacture, process, distribute in commerce, use, or dispose of PCB's, including local, state, and Federal Government.

**10.4.2. Classification for disposal of materials containing PCB's.-** The final rules and regulations define the following three classes of transformers containing dielectric fluid and disposal requirements:

1. The PCB transformers.- Transformers containing dielectric fluid with over 500 mg/L (p/m) PCB. These transformers may not be repaired or rebuilt and the dielectric fluid must be disposed of in an incinerator which complies with Annex 1 of the rules and regulations. The transformer itself may be incinerated in the same manner as the fluid or may be disposed of in a chemical waste landfill that complies with Annex II of the rules and regulations.

2. The PCB-contaminated transformers.- Transformers containing dielectric fluid that has between 50 and 500 mg/L PCB. These transformers may be rebuilt and are not required to have an askarel warning label. Dielectric fluid from a PCB-contaminated transformer may be incinerated in an incinerator that complies with Annex I, disposed of in a chemical waste landfill that complies with Annex II, or disposed of in a high-efficiency boiler that complies with EPA criteria.

3. Non-PCB transformers.- Transformers that contain less than 50 mg/L PCB. No transformer may be considered to be a non-PCB transformer unless its dielectric fluid has been tested or otherwise verified to contain less than 50 mg/L PCB. The EPA rules and regulations do not apply to non-PCB transformers, except the EPA rules do apply and prohibit the use of waste oil containing any detectable PCB's as a sealant, coating, or dust-control agent.

It is recommended that all Reclamation oil-filled transformers be tested to determine if the dielectric fluid is PCB contaminated prior to the disposal of the transformer and/or the dielectric fluid. Although EPA regulations do not require that this test be performed, they state that the dielectric fluid must be considered to be PCB contaminated if the test is not performed and the EPA disposal regulations would then apply to it.

**10.4.3. Shipment of PCB scrap liquids for disposal.-** All liquid scrap PCB should be placed in appropriate metal transport drums, properly labeled, for shipment to a company offering an acceptable disposal service.

**10.4.4. Shipment of solid waste materials containing PCB's for disposal.-**Material of this type should be placed in open-head drums and suitable closures and with the drums properly labeled for shipment to a company offering an acceptable disposal service.

**10.4.5. Liquid and solid waste disposal service organizations.-**

a. General.-An updated list of facilities approved by the EPA to dispose of PCB waste consisting of capacitors, properly drained transformers, contaminated soil, dirt, rags, asphalt, properly drained containers, and other debris is published in the Federal Register approximately every month. For further information on the EPA approval of disposal facilities, please get in touch with the appropriate EPA regional office.

b. Costs.- In addition to the normal costs of collecting PCB scrap liquids and solids for disposal, additional costs borne by the owner of such scrap including shipping containers, cost of transport to the disposal service organization, and a disposal fee.

## PART III - SYNTHETIC INSULATING LIQUIDS

### 11. SILICONE OIL

Polydimethylsiloxane Fluid (silicone oil) has been accepted by OSHA as a substitute for askarel. This synthetic fluid compares favorably with askarel and oil for use as a coolant, with a fire safety rating better than oil but slightly less than askarel. The viscosity of silicone fluid is higher than that of oil or askarel. Although long-term health studies have not been completed, the test data available indicate that the silicone fluid does not have the serious health effects associated with askarel. Because of the lack of definitive knowledge of the long-term effects, it is suggested that chronic exposure of a continuous nature be avoided whenever possible. The main health problem known is the potential eye irritant effects of silicone and the fact that it can be easily transferred to the eyes since it does not readily wash off the hands. It is therefore suggested that the following precautions be taken:

- a. Employees should be warned that the substance is not removed by ordinary soap and water and that transfer to the eyes can cause irritation.
- b. Labels containing the above warning and instructions for removal from the skin should be on every container.

### 12. RETROFILLING TRANSFORMERS WITH SILICONE OIL

Several companies are retrofilling oil and askarel-filled transformers with silicone fluid. The following items must be taken into consideration if a retrofill is desired:

- a. Due to the higher viscosity, the heat transfer of silicone is not as good as oil or askarel. Therefore, to avoid a higher temperature, a transformer will have to be either derated or be provided with additional cooling capacity.
- b. Where direct substitution of silicone liquid is made for oil or askarel in a transformer, the loading capability of the transformer may be reduced up to 10 percent.
- c. Some types of pumps will wear very rapidly when used to pump silicone fluid. Acceptability of a pump must be checked for service as a transformer-silicone-oil pump.
- d. Gasket and bushing combinations used with askarel and transformer oils, such as cork and asbestos-impregnated cork, are compatible and not injured by silicone fluid. Conventional silicone rubber gaskets and bushings cannot be used with silicone oil because they swell excessively.

e. Silicone- filled transformers require no special maintenance, and standard maintenance procedures developed for oil-or askarel-filled transformers will generally apply.

f. Residual PCB in an askarel-filled transformer will not leach out into the silicone fluid where it could be filtered

out or otherwise removed. As a result, the transformer itself will remain a PCB item as far as disposal requirements are concerned.

It is suggested that any project office considering a change to silicone oil contact the Facilities Engineering Branch, Denver Office, for advice.

# APPENDIX A

## SAMPLING PROCEDURES

The validity of test results is dependent upon being certain that the oil sample is truly representative of the oil in the equipment. Thus, it is essential that the sample container of whatever type be free of contaminants, that the point of sampling within the equipment will produce a representative sample, and that sampling taps and connecting tubing be purged before a sample is taken.

Ordinarily, samples for physical tests can be taken in 1-Liter (1 qt) glass bottles. Glass bottles are recommended as containers for samples because they can be easily inspected for cleanliness. The glass bottles may be either cork or glass stoppered to fitted with screw caps having cork or aluminum liners (inserts). Corks should be of good quality. DO NOT use rubber stoppers. Gas-in-oil samples may be taken in 150- or 1,000-m/L stainless steel cylinders (glass syringes and other samplers have been used by others). The 1,000-m/L cylinders provide enough sample for both physical and gas-in-oil tests.

Containers should be rinsed in chloroethene or another comparable nonflammable solvent, dried, and washed in strong soapsuds. Then they should be thoroughly rinsed with water, dried in an oven at about 105 EC (220 EF) for several hours, and removed from the oven. They should be corked while still warm. As the bottles cool, they should be sealed by dipping the necks

in wax; then, the bottles should be stored for future use.

These bottles should be opened only when the bottle temperature and the ambient temperature are the same.

Because of the importance of properly cleaned and treated containers, laboratory-approved containers should be used.

**A-1. SAMPLING OIL FROM TRANSFORMERS AND CIRCUIT BREAKERS FOR PHYSICAL TESTS.**- The following general sampling instructions should be followed:

- a. At least 2 L (2 qts) of oil should be taken as a sample for dielectric, acidity, and IFT tests. Allow space at the top of the container for expansion. If two 1-L (1-qt) bottles are used for a sample, label the bottles "1 of 2" and "2 of 2."
- b. Samples from outdoor apparatus should be taken on clear days when the humidity is near normal and the oil is at least as warm or warmer than the surrounding air. Cold oil may condense enough moisture from a humid atmosphere to seriously affect its insulating properties and hot oil may absorb enough moisture from the air to give very inaccurate results when cooled to room temperature.

c. Samples should never be drawn in rain or when the relative humidity of the atmosphere exceeds 70 per-cent.

d. Guard against wind and dust.

e. When taking samples from an opening, such as a valve, clean the valve thoroughly and allow enough liquid to run out [about 1 L (1 qt)] to remove any moisture or foreign material, f. In a sealed transformer, which has a vacuum, be sure to vent the transformer before drawing the sample.

g. Place sample in the freezing compartment of a refrigerator overnight. If the sample is cloudy when viewed the next day, it contains free water. Since free water is undesirable, take another sample to determine whether water is in the oil or was in the sample container.

## **A-2. TAKING OIL SAMPLES FOR GAS-IN-OIL ANALYSIS.-**

a. Purpose.- This procedure has been developed to maintain uniformity of all oil samples taken in the field for a laboratory gas-in-oil analysis.

b. General.-Special stainless steel containers are to be used for collecting samples of oil for gas-in-oil analysis using the gas chromatograph. These stainless steel containers are NOT to be used for any other purpose. The Materials Science laboratory cleans these

containers to eliminate all contaminants and purges them with dry air for shipment to the field.

### **c. Preparation for Sampling.-**

(1) Obtain a can to catch overflow oil from the stainless steel container.

(2) Obtain two lengths of clear plastic tubing and attach one to each end of the stainless steel container. Make certain that the tubing between transformer and container is as short as possible.

### **d. Sampling Procedure.- Modification of transformer sampling tap may be necessary before sample can be obtained (fig. A-1).**

(1) Connect the shortest enclosed plastic tube to valve No. 3 and fasten the connector sleeve for a tight seal.

(2) Open valve No. 3 and purge about 1 L (1 qt) of oil or until oil is clear and free of bubbles.

(3) With the tube still full of oil, connect it to valve No. 2.

(4) Connect longer tygon tube to valve No. 1.

(5) Hold the cylinder in a vertical position for filling. During filling, it should be tipped gently back and forth to vent any trapped bubbles.

(6) To fill the cylinder, open valves in the following order: 1,2, and 3.

(7) Allow at least 4 L (1 gal) of oil to flow through the cylinder before closing the valves. Close valves in the same order (i.e., 1, 2, and 3).

(8) For disassembly:

(a) Remove and drain tubing.

(b) Pack cylinders and tubing in shipping box, as received.

(c) Fill out data sheets for all samples and seal them in the oil-proof plastic envelope.

### **A-3. TAKING GAS SAMPLES FOR GAS CHROMATOGRAPH ANALYSIS.**

a. Purpose.- This procedure has been developed to maintain uniformity of all gas samples taken the field, while keeping in mind the principal objective of obtaining a true and representative sample that is completely free of contaminants.

b. General.- Special stainless steel or glass cylinders are to be used for collecting samples of gas for use with the gas chromatograph. These containers are NOT to be used for any other purpose. The Materials Science laboratory cleans these containers to eliminate all contaminants. These sample cylinders are filled with dry nitrogen when they are sent to the field. The opening and closing of the exhaust valve on the cylinder, as required in the procedure, is to create turbulence such that a "washing" action will occur and remove the nitrogen. The purging and "washing" is required to ensure that a true and representative sample is obtained.

Special care should be taken to avoid getting moisture in the sample since moisture can damage the analyzing equipment.

c. Sampling Procedure.- If the gas system is under positive pressure, the following procedure applies; but, if the gas system is at atmospheric or negative pressure refer to part II.

## PART I

(1) Attach a minimum length of clear plastic sample tubing to the transformer sampling line cock. In most cases, approximately 152 mm (6 in) will be adequate.

(2) Open the transformer sampling line cock and purge the plastic sampling tube for 15 seconds.

(3) Connect the sampling cylinder, with both valves closed, while the plastic sampling tube is still exhausting.

(4) Open petcock on transformer end of sampling cylinder.

(5) Open petcock on outlet end of cylinder for 2 or 3 seconds, then shut off. Repeat this step five times.

(6) Close both valves on sampling cylinder (outlet end first, then transformer end). Close transformer sampling cock and remove sample cylinder and connecting tubing.

(7) **DO NOT** wrap **ANY** kind of tape around valves or filling nozzles of the sample cylinders.

(8) Identify samples. List air temperature at sampling time and approximate elevation.

## PART II

This procedure should be followed if the gas sample is at atmospheric or negative pressure.

(1) Attach a minimum length of clear plastic sample tubing to the transformer sampling line cock. In most cases, approximately 152 mm (6 in) will be adequate.

(2) With both valves closed, connect the sampling cylinder to the plastic sampling tube.

(3) The sample must be drawn with a vacuum pump or with a hand aspirator bulb with a one-way valve connected to the outlet end of the container instead of the bladder.

(4) One valve on outlet end of sampling cylinder while the vacuum pump (or hand aspirator) is in operation. With the sampling cylinder completely evacuated, close the petcock on outlet end of sampling cylinder.

(5) Open transformer sampling cock for 2 or 3 seconds, then shut off. Repeat this step five times.

(6) Close petcock on transformer end of sampling cylinder. With all petcocks closed, remove sample cylinder and connecting tubing.

(7) **DO NOT** wrap **ANY** kind of tape around petcocks or filling nozzles of the sample cylinders.



(8) Fill in tag attached to container and put container in shipping box.

**A-4. SAMPLING OIL FROM DRUMS OR SHIPPING CONTAINERS.**

- The oil drum should remain undisturbed for several hours before drawing the sample.

a. A glass or Pyrex thief is recommended for sampling, because it can be easily inspected for cleanliness. A glass tube approximately 910 mm (36 in) long, 25 mm (1 in) in diameter, and tapered at both ends is recommended for the sampling thief.

b. The thief should be cleaned before and after sampling in the same manner as cleaning sample containers. When not being used, the thief should be corked at both ends.

c. Discard the first full thief of oil.

d. Draw the sample in the following manner:

(1) With the top end covered with the thumb, lower the tube to within approximately one-eighth inch from the bottom of the drum.

(2) Remove the thumb from the top opening until the thief is filled with oil.

(3) Replace thumb over top of thief and remove thief full of oil to the sample container. Release thumb to permit oil to run into the container.

**A-5. SHIPPING.** - Samples for test should be sent:

a. First class mail. (Containers of combustible gas cannot be shipped by air or parcel post.)

b. Federal Express.

c. United Parcel Service.

## APPENDIX B

### DIELECTRIC TEST EQUIPMENT AND METHODS

**B-1. GENERAL.**- Since dissolved water cannot be detected by dielectric test, and the dissolved water emulsifies out at lower temperatures, the temperature of the oil for testing should be nearly the same for each test in order to obtain consistent results. The temperature range for testing the oil should be between 20 and 30 EC (68 and 86 EF). Dielectric tests should be conducted in accordance with ASTM D 877. For convenience, this standard (as applicable to Reclamation) is presented below. B-2.

#### **B-2. DIELECTRIC TEST - ASTM D 877 (Disk Electrodes).**

a. Scope.- This method of testing electrical insulating oils applies to oil of petroleum origin for use in cables, transformers, oil circuit breakers, and similar apparatus as an insulating or cooling medium, or both.

b. Apparatus (Manual Tester). Portable oil dielectric tests are usually used for making dielectric tests on oil in the field. Units with a variable high voltage of 40 kV or greater between the electrodes and which have Bakelite test cups are considered satisfactory. The following instructions cover the adjustment and care of the electrodes and test cup:

- (1) The electrodes and the test cup shall be wiped clean with dry,

calendared tissue paper or with a dry chamois. The spacing of the electrodes shall be checked with a standard round gauge having a diameter of 2.54 mm (0.100 in) or with flat steel "go" and "no go" gauges having thicknesses of 2.53 and 2.55 mm (0.0995 and 0.1005 in) respectively; the electrodes shall be locked in position. It is important to avoid touching the electrodes or the cleaned gauges with the fingers or with portions of the tissue paper or chamois that have been in contact with the hands. The electrodes and test cup shall be rinsed with Stoddard solvent or chloroethene until they are entirely clean. To avoid any possible contamination, care shall be taken to avoid touching the electrodes or the inside the cup after cleaning. After a thorough cleaning, the test cup shall be filled with a sample of the cleaning fluid; voltage shall be applied and uniformly increased at a rate of approximately 3 kV/s (rms value) until breakdown occurs. If the breakdown is not less than the established value of the oil being tested, the test cup shall be considered in suitable condition for testing. If a lower value is obtained, the cup shall again be thoroughly cleaned and the test repeated. A cleaning fluid whose breakdown is not less than the established value of the oil being tested must be used.

(2) At the beginning of each day's testing, the electrodes shall be examined for pitting and carbon accumulation, and the electrode spacing shall be checked. The test cup shall be thoroughly cleaned and tested as described in [subparagraph B-2.b.\(1\)](#). It shall then be flushed with a portion of the sample to be tested before it is filled for the test.

(3) If the test of a sample is below the breakdown value being used by the operator as a minimum satisfactory value, the cup shall be cleaned and prepared as described in [subparagraph B-2.b\(1\)](#) before testing the next sample.

*NOTE:* Evaporation of the cleaning fluid from the electrodes may chill them sufficiently to cause moisture to condense on their surfaces. For this reason, after the final rinsing with cleaning fluid, the cup must immediately be flushed with the oil to be tested and then filled for the test.

#### c. Procedure.-

(1) *Preparation of Sample.* The dielectric strength of liquid dielectrics may be markedly altered by the migration of impurities through the liquid. In order that representative test specimens may be obtained, the sample container shall be gently tilted or inverted and the oil swirled several times before each filling of the test cup, in such a way that any impurities present will be thoroughly mixed with

the dielectric. Too rapid agitation is undesirable, since it introduces an excessive amount of air into the liquid. Immediately after agitating, the test cup shall be filled with oil to a height of not less than 20 mm (0.787 in) above the top of the electrodes. In order to permit the escape of entrapped air, the container shall be gently rocked a few times and the oil allowed to stand in the cup for 3 minutes before voltage is applied.

*NOTE:* It is impracticable to handle oils having viscosities ranging between 60 and 100 Sus at 99 EC (210 EF) according to the procedure in section B-2.c.(1). When testing high-viscosity oils in this range, the sample should be allowed to stand until it reaches room temperature, which should not be less than 20 EC (68 EF). The sample container should not be tilted or swirled as prescribed in section B-2.c.(1), and it should be opened only when the sample is ready for testing. The size of the sample should be selected so that the final cup filling will contain the normal drainings from the container.

(2) *Test Temperature.* The temperature of the sample when tested shall be the same as that of the room, but shall not be less than 20 EC (68 EF). Testing of oil at a temperature lower than that of the room is likely to give variable results which may be misleading.

(3) *Application of Voltage.* Voltage shall be applied and increased at a uniform rate of 3 kV/s from zero until breakdown occurs as indicated by a continuous discharge across the gap. Occasional momentary discharges which do not result in a permanent arc may occur; they should be disregarded.

d. Number of Tests.-

(1) *Referee Testing.* When it is desirable to determine the dielectric breakdown voltage of a new liquid for referee purposes, one breakdown shall be made on each of five successive fillings of the test cup. The breakdown voltage thus obtained shall be subjected to the criterion for statistical consistency as specified in section B-2.d(4). If the five values meet this criterion, their average shall be reported as the dielectric breakdown voltage of the sample. If they do not meet this criterion, one breakdown on each of 5 additional cup fillings shall be made, and the average of the 10 breakdowns shall be reported as the dielectric breakdown voltage of the sample. No breakdown shall be discarded.

(2) *Routine Testing.* When it is desired to determine the dielectric breakdown voltage of a liquid on a routine basis, one breakdown may be made on each of two fillings of the test cup. If no value is below the specified acceptance value, the oil may be considered satisfactory, and

no further tests shall be required. If either of the values is less than the specified value, a breakdown shall be made on each of three additional cup fillings, and the test results analyzed in accordance with section B-2.d.(1).

(3) *Routine Testing (Alternative Method).* When it is desired to determine the dielectric breakdown voltage of a liquid on a routine basis, five breakdowns may be made on one-cup filling with 1-minute intervals between breakdowns. The average of the five breakdowns shall be considered the dielectric breakdown voltage of the sample, provided the breakdown values meet the criterion for statistical consistency as specified in section B-2.d.(4). If the breakdown voltages do not meet this criterion, the contents of the cup shall be discarded, the sample container again gently inverted and swirled, the cup again filled, and five breakdowns made on this second-cup filling. The average of the 10 breakdowns shall be considered as the dielectric breakdown voltage of the sample. No breakdown shall be discarded.

(4) *Criterion for Statistical Consistency.* Compute the range of the five breakdowns (maximum breakdown voltage minus minimum breakdown voltage), and multiply this range by 3. If the value obtained is greater than the next to the lowest breakdown volt-

age, it is probable that the standard deviation of the five breakdowns is excessive, and therefore, the probable error of their average is also excessive.

e. Report. - The report shall include the following:

(1) Procedure used,

(2) The voltage (rms value) at each breakdown and the average of the five(or 10) breakdowns. All results shall be reported to the nearest kilovolt, and

(3) The approximate temperature of the oil at the time of the test.

**B-3. DIELECTRIC TEST - ASTM D 1816 (VDE Electrode).**- The present ASTM D877 gap consists of a 25.4-mm- (1-in-) diameter disk, square-edged electrodes spaced at 2.54 mm (0.1 in). Use of this test gap results in a uniform electrostatic field at the centerline of the test disks, and a highly nonuniform field at the edges of the disks. To attain a uniform field strength at all points, spherical electrodes would have to be used. Between these extremes of a highly distorted field and an ideal uniform

field, a third gap configuration, designed at VDE or ASTM D 1816, has been used. The VDE gap specifications call for a sector diameter of 36 mm (1.4 in) and a 25-mm (1-in) radius of curvature for the spherically capped electrodes. A gap of about 2 mm (0.08 in) between electrodes has been found to give about the same breakdown voltage relationships in the 25- to 30-kV range as the ASTM D 877 configuration. Tests have shown that:

a. The VDE configuration depicts more accurately the average electric strength and scatter of the oil as the transformer sees it,

b. The VDE gap is relatively sensitive to oil quality; the ASTM D 877 gap is less sensitive, and

c. Point electrodes are almost completely insensitive to oil quality. The VDE cell, in which a quart of oil is tested between VDE electrodes, while being mildly circulated, realistically measures changes in oil strength which determine the electrical strength of typical transformer construction. This test method (ASTM D 1816) is presently used only as a laboratory test and research tool by Reclamation.

## APPENDIX C

### ACIDITY TEST EQUIPMENT AND METHODS

#### C-1. FIELD TEST PROCEDURE FOR NEUTRALIZATION NUMBER (Acidity).-

a. Gerin Oil Acidity Test.- The acid number (commonly called neutralization number) is the mass of KOH (potassium hydroxide) in milligrams required to neutralize the acids in 1 gram of oil; for example, 0.3 mg of KOH per gram of oil.

With the Gerin test kit (fig. C-1), the oil sample instead of being weighed



**Figure C - 1. - A Gerin test kit with two bottles of neutral solution, four glass mixing cylinders, and seven ampules of KOH solution. Photo P801-D-74915**

is more conveniently poured into a graduated glass cylinder. Single doses of KOH are furnished in sealed ampules and the dosage is indicated by the number imprinted on the ampule. With the glass cylinder filled with oil to the level marked 10, and a No. 3 ampule added, a mixture is obtained which equals 0.3 mg of KOH per gram of oil; a No. 6 ampule added equals 0.6 mg; and a No. 15 ampule added equals 1.5 mg of KOH per gram of oil.

The neutral solution is to be put into the measured sample before adding the KOH. This solution "washes" the oil, and the KOH can then act on the acids more readily. The neutral solution contains a color-changing indicator. If any KOH is left after the acids are neutralized, the indicator is pink; but if the KOH is all used up, the indicator is colorless like water.

b. Reclamation Modification of Gerin Test for Neutralization Number Range 0.6 to 0.05.- The following modification of the Gerin Corp. oil acidity test procedure has been useful in determining the neutralization number (acidity) of oils ranging between 0.6- and 0.05-mg KOH per gram of oil.

(1) *Apparatus.* A 100-mL, graduated, glass cylinder (fig. C-2)(1) with standard taper, pennyhead stopper also graduated in millili-

ters. Each tenth graduation mark completely encircles the cylinder; the cylinder has a hexagonal base. (Van Water and Rogers, catalog No. 24760-100). (2) Gerin neutral solution. (3) Gerin No. 3 ampule.

(2) *Procedure.*- Pour oil into the glass cylinder (fig. C-2) until the bottom of the curved surface of the oil is level with the 5-mL mark. Add neutral solution to bring the curved surface up to the 35-mL mark, place stopper in cylinder, and mix well; add contents of a No. 3 ampule, place stopper in cylinder, and shake vigorously for 8 to 9 seconds. As soon as any neutral solution separates from the oil (and settles to the bottom of the cylinder) notice its color. If the solution is colorless or yellow, the acidity is greater than 0.6. (A sample of an oil having an acidity of 0.3 or greater should be sent to the Denver Office Laboratories, Attn D-3743.)

If the solution is pink, add another 5 mL of oil to the cylinder, shake, and note color. If colorless or yellow, the acidity is between 0.6 and 0.3. If the color is pink, add oil in 10-mL increments until the neutral solution becomes colorless or yellow. Using the total milliliters of oil placed in the cylinder, refer to the following table for the acidity.

Sixty milliliters of oil in addition to the 35 mL of neutral solutions is as much liquid as a 100-mL cylinder can handle efficiently.

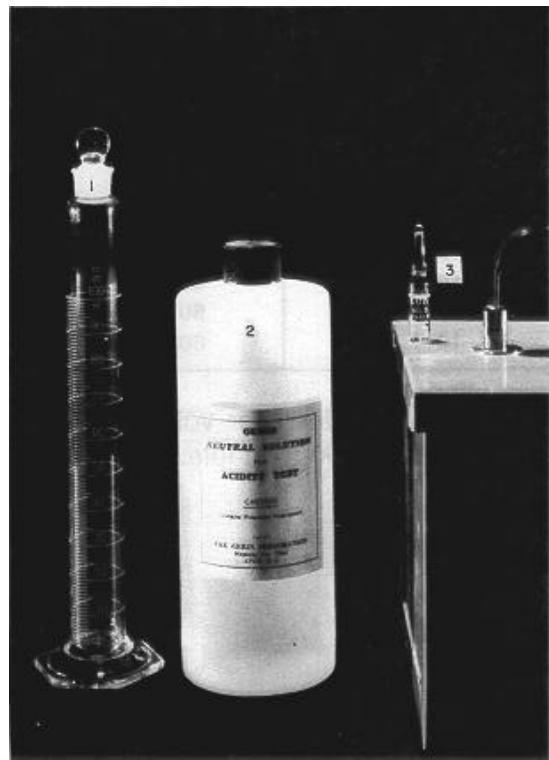


Figure C-2. - Equipment for determining acidity (neutralization number) by the Reclamation modified Gerin test method. (1) 100 mL glass cylinder (2) Gerin neutral solution, and (3) No. 3 ampule. Photo P801-D-74916

If the mixture is red or pink and a lower acid value is desired, allow the solutions to separate. Carefully pour off about three-fourths of the upper layer and continue the test. This procedure may be repeated until the volume of the lower layer falls below 15 mL. This procedure is useful for determining the approximate acidity from 0.6 to 0.010 using only one No. 3 ampule. The graduations on the cylinder may be used to measure the increments of oil. The following equation may be used to calculate

mL increments of oil	Total mL of oil in cylinder	Color colorless or yellow acidity greater than	Color red or pink acidity less than
5	5	0.6	
5	10	0.3	0.3
10	20	0.15	0.15
10	30	0.10	0.10
10	40	0.075	0.075
10	50	0.06	0.06
10	60	0.05	0.05

acidity values for volumes of oil not listed in the table:

$$\text{Acidity} = \frac{C}{V} \times A$$

where:

C = 10 (calibration value of ampule based on a 10-mL sample),

V = Volume (total milliliters of oil used in test), and

A = KOH value of ampule

Example No. 1 Sample was light pink with 20-mL volume of oil.

$$\frac{10}{20} \times 0.3 = \frac{3}{20} = 0.15$$

(Acidity of the sample is less than 0.15.)

An additional 5 mL of oil turned the solution yellow. The total volume of oil now in the cylinder is 25 mL.

$$\frac{10}{25} \times 0.3 = \frac{3}{25} = 0.12$$

The acidity of the oil is reported as greater than 0.12 and less than 0.15.)

Example No. 2.

A 10-mL sample of oil-tested acid (yellow) to a No. 3 ampule indicating that the acidity was greater than 0.3. The operator wished to check the acidity more accurately. The first test was discarded and a new test started using a 5-mL sample of oil and a new No. 3 ampule. The neutral solution was red showing an excess of KOH and indicating that the acidity was between 0.3 and 0.6. Using the graduations on the cylinder, oil was added in 1-mL increments. The red color lightened after each increment was added. The color after adding the third increment (a total of 8 mL of oil in the cylinder) was a faint pink indicating that the end point was near. An additional milliliter of oil (9 mL total) removed all traces of pink indicating that the KOH had been neutralized and that the contents of the cylinder were slightly acid.

Using the equation:



The acidity of the 8 mL of oil (pink) equals

$$\frac{10}{8} \times 0.3 = \frac{3}{8} = 0.375$$

The acidity of 9 mL of this oil (yellow) equals

$$\frac{10}{9} \times 0.3 = \frac{3}{9} = 0.333$$

Therefore, the acidity of this oil is greater than 0.333 and less than 0.375-mg KOH/g oil.

c. **Safety Precautions.**- This test procedure involves the use of glassware and poisonous chemicals which are potentially dangerous. However, an operator having been alerted to these hazards and who applies the following safety techniques should experience no injuries.

(1) *Glassware.* Sweep up fragments of broken glassware; DO NOT attempt to pick up splinters of glass with the fingers. Discard any glassware that has sharp edges that could cause cuts. The following procedure is suggested when glassware breaks which contained chemical solutions. Wear rubber gloves if available. Sweep up the broken glassware. Pick up liquid with an absorbent material (mop, cloth, paper towels, etc.) Flush area with water and pick up the excess water with an absorbent material. If a mop and broom or brush have been used, rinse mop head broom or brush with water. If cloth,

paper towels, etc., have been used, place them in a trash can. Rinse gloves with water. Wash hands thoroughly.

(2) *Chemicals.* Both chemicals (neutralizing solution and KOH) are poisonous and care should be exercised to keep them out of the eyes and mouth. The KOH in the ampules is caustic and has the same effect on the skin as household lye if it comes in contact with the skin. It should be removed immediately by flushing the area with water until the slick soapy feeling disappears. Applying vinegar to the area covered with KOH rapidly neutralizes the caustic and is the quickest way to stop a caustic burn.

(3) *Opening KOH Ampules.* DO NOT open ampules with the bare hands. The bottom of the ampule has been known to break and inflict a severe cut. The procedure for opening ampules described below has proved to be safe.

Always keep the ampule in an upright position so that the KOH solution cannot get into the top portion of the ampule. Prior to breaking the bottom off of the ampule, the operator should be protected by paper towels, cloth, or other absorbent material. To break ampule, place thumbs as close as possible to the scored circle on the ampule and exert an outward pressure; at the same time, pull with the index and middle fingers of the hand holding the top of the ampule.

## APPENDIX D

### IFT TEST EQUIPMENT AND METHODS FOR FIELD USE

#### D-1. THE IFT TEST OF OIL BY THE DROP-WEIGHT METHOD (ASTM D 2285).-

a. Scope.- This method describes a comparatively rapid procedure applicable to field use for measuring, under nonequilibrium conditions, the IFT (interfacial tension) of electrical insulating oils of petroleum origin against water.

b. Summary of Method.- The IFT is determined by measuring the volume of a drop of water that the oil will support. The larger the drop of water, the higher the IFT of the oil. The instrument used to measure the volume of the drop of water is calibrated in newtons per meter to indicate the approximate IFT.

*NOTE 1:* This method is based on the use of PTA (Professional Technical Associates) (P.O. Box 123, Signal Mountain, Tennessee) model VI a or V2; other equivalent-type tensiometers may be used with appropriate modifications in procedure.

#### D-2. DETAILED EXPANSION OF PTA MODEL 6 TENSIO-METER. -

a. Apparatus.- The PTA model 6 IFT (fig. D-1) has been accepted by ASTM as a suitable substitute for the models VI a and V2. The primary features have been preserved: no changes in

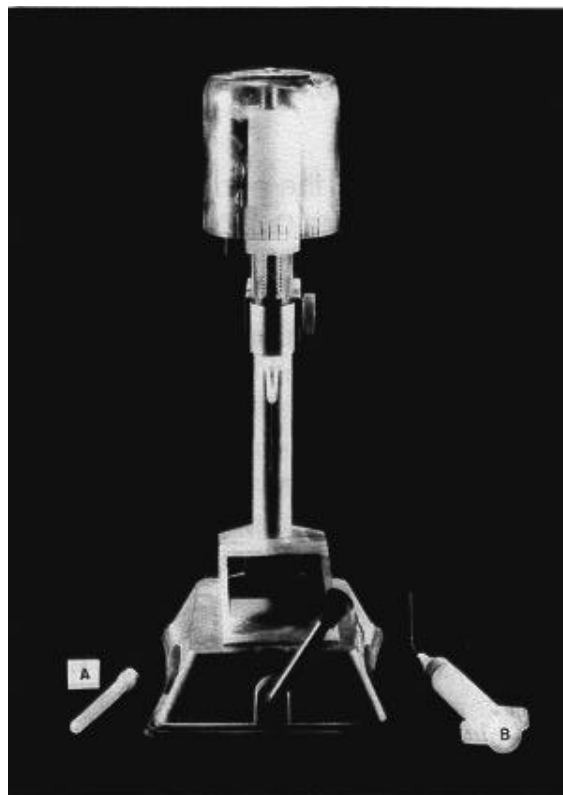


Figure D1, - The model 6 PTA interfacial tensiometer mounted in support stand. The syringe (B) with bent needle is used for filling the tensiometer barrel. The tubing orifice cover (A) is shown on the left side of the support stand. The cover should be placed over the orifice needle when the instrument is not in use. Photo P801 -D-74917

the method used in ASTM D 2285 are involved. The model 6 features an almost unbreakable dial (fig. D-2) made of polycarbonate (Lexan). The dial has 50 calibrations and two number scales.

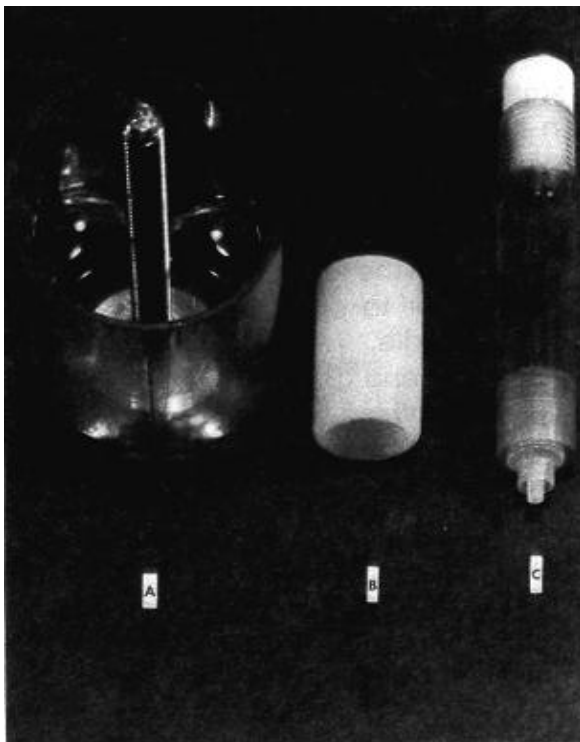


Figure D-2.- Dismantled tensiometer. (a) Polycarbonate (Lexan) dial with micrometer screw attached. (B) Teflon lead nut. (C) Tensiometer barrel with white Teflon plug. Photo P801-D-74918

Each small calibration line represents 0.001 N/m (1 dyn/cm) therefore, with the double scale, each number represents 0.01 N/m (10 dyn/cm) and should be considered as 0.01, 0.02, 0.03, etc. Values from 0 to 0.0499 N/m (0 to 49.9 dyn/cm) are read from the lower scale. Values from 0.05 to 0.0999 N/m (50 to 99.9 dyn/cm) are read on the upper scale.

The vacuum base permits the tensiometer to firmly grip any smooth surface. The tensiometer is extremely stable and is lightweight, it weighs 850 g (30 oz).

The orifices of the model 6 have the same dimensions as previous models but are machined with a Luerlock (fig. D-3) which permits easy filling of the barrel; a spare orifice is provided; and a syringe, (B) in figure D-1 provides for easy filling of the tensiometer barrel.

b. Operation Problems and Solutions.- Prior to using the tensiometer for the first time, dismantle the instrument as shown in figure D-2. Be certain that the white Teflon nut on the top of the barrel, (C) of figure D-2, is screwed tightly into the barrel.

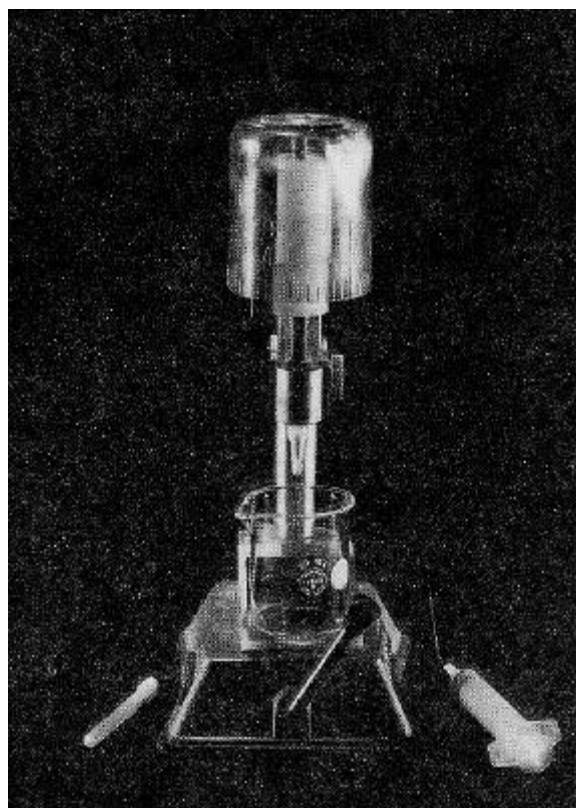


Figure D-3. - Tensiometer with 50-mL beaker under the tubing orifice. Handle in front operates the section base. Orifice with Luerlock is attached to bottom of barrel and extends into beaker. Photo P801-D-74919

Check the top of the nut for sufficient Vaseline for sealing. If Vaseline is present, reassemble the unit; if not, add sufficient Vaseline to form a good seal when (B) and (C) are fastened tightly together.

*(1) Problems and Corrective Measures to be Taken.-*

(a) Water dripping from orifice.- Check Vaseline seal (between Teflon plug and lead nut).

(b) Micrometer screw turns but will not advance.- Dismantle tensiometer and tighten packing nut (B) and white Teflon nut on top of tensiometer barrel (C).

(c) Excessive deviations in scale readings during calibration.- Check orifice for dirt and lint; check Vaseline seal.

c. Filling Tensiometer Barrel with Water.  
-The orifice (A) and pointer (B) (fig. D-4) are removed, the micrometer screw is backed out to maximum position, the tensiometer is inverted, and the barrel is filled to overflowing with approximately 25 EC (77 EF) distilled water using the filler syringe which has a bent needle for this purpose. At this point, inspect the interior of the barrel for air bubbles. (It is rare that no bubbles are present.) To remove these small air bubbles: Push the plunger of the filler syringe into the syringe barrel as far as it will go. Place the tensiometer in the inverted position; insert the needle of the filler syringe into the tensiometer barrel; then using the plunger of the syringe, remove about 5 to 10 percent of the water. Place the tensiometer in a horizontal position and

by tilting the tensiometer barrel, pick up the small air bubbles by passing the large air bubble (formed by removing the water from the barrel) over the small bubbles. Place the tensiometer in the inverted position. Fill the filler syringe with water and expel air bubbles. Place the end of the bent needle of the filler syringe under the surface of the water in the tensiometer and fill the tensiometer to overflowing and withdraw needle. Attach pointer and orifice, (A) and (B) of figure D-4. Turn dial until nothing but water is expelled from the orifice. The tensiometer should now be free of air. Place in holder.

d. Calibration of Tensiometer.- The tensiometer full of distilled water at 25 EC (77 EF) and void if air is placed in the mounting stand (fig. D-1). The 50-mL beaker containing at least 1/2 inch of distilled water is placed on the beaker platform of the mounting stand. The tensiometer is lowered until the tip

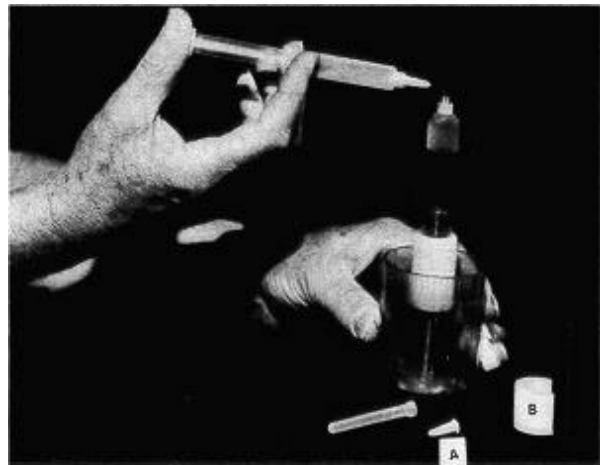


Figure D-4. - Technique for filling tensiometer barrel with distilled water. Photo P801-D-74920

of the orifice is within 6.4 mm (0.25 in) of the surface of the water (fig. D-3).

The temperature of the water in the orifice may differ from that of the water in the tensiometer; therefore, replace the water in the orifice by turning the dial clockwise until five drops of water have been expelled. Stop all movement of the dial immediately as the last drop leaves the orifice tip.

Record the reading on the scale, then expel a single drop of water and record scale reading. Second reading minus first reading equals the volume, in terms of divisions on the scale, of a drop of water expelled in air.

The average of 10 such "drops in air" is taken as the orifice calibration of water in air. Any reading deviating as much as 0.20 from the average is discarded; and if any reading is as much as 0.40 from the average, the whole series is discarded and the cause of such deviation determined. Leakage of air is the usual source of variation, with dirt and lint on the orifice also a possible cause. The calibration drop should be checked once each day that the tensiometer is to be used in order to assure accurate results. The calibration drop should be determined prior to starting the day's testing program because the calibration procedure not only obtains the drop volume, in terms of divisions on the scale, but also is an indicator as to the performance of the instrument. An instrument that is not functioning properly will not produce drops within the following specifications limits of

the test procedure. An example of determining the calibration drop follows:

A = Dial reading before expelling drop.

B = Dial reading after expelling drop.

C = B - A (Scale divisions per drop of water in air. Average of 10 drops equals the calibration of tensiometer.)

	B	-	A	=	C
1.	40.0	-	31.2	=	8.8
2.	49.0	-	40.0	=	9.0
3.	58.2	-	49.0	=	9.2
4.	67.1	-	58.2	=	8.9
5.	76.1	-	67.1	=	9.0
6.	85.3	-	76.1	=	9.2
7.	94.5	-	85.3	=	9.2
8.	53.6	-	44.5	=	9.1
9.	62.8	-	53.6	=	9.2
10.	71.8	-	62.8	=	<u>9.0</u>
					9.06

Dividing the total by 10 (the number of drops), the resulting number (9.06) represents the average of the 10 readings which is the calibration value of the tensiometer. Subtracting reading No. 1 (8.8) from the average (9.06) the difference (0.26) is greater than the specified 0.20 and the 8.8 reading should be discarded. Another drop was measured and the value of this drop (0.1) replaced the 8.8 drop. The final total for 10 drops was 90.9 raising the new calibration value from 9.06 to 9.09.

(1) *Important Instruction.* - Review the tensiometer settings from the

above example for drops 7 and 8. It is evident that the A and B settings for drop 7 are a continuation of the settings of preceding drops; however, the A and B settings for drop 8 are decidedly different. Tensiometer readings under 100 divisions are desirable. It was evident that an additional nine divisions added to the B setting (94.5 divisions) for drop 7 would give a value of 103.5 divisions. An examination of the tensiometer will show that 94.5 on the upper scale of the dial corresponds to 44.5 on the lower scale. This is the technique used in order to avoid tensiometer readings in excess of 100 divisions. Reviewing the data listed above, it will be noted that values for drops 1 and 2 were taken from the lower scale whereas for drops 3, 4, 5, 6, and 7, the upper scale was used. The value for 8A was taken from the lower scale, the remaining values 8B through 1013 were from the upper scale.

e. Apparatus Preparation Prior to Testing Oil Samples.- Place the tensiometer with orifice attached (the unit should be full of water and free of air bubbles) in the holder. Wipe the tensiometer tubing orifice free of oil with clean lint-free paper, avoiding any upward motion which may embed a bit of fiber on the sharp orifice.

**CAUTION:** Do not use an oil solvent on the orifice or barrel.

Force a few drops of water through the orifice by turning the polycarbonate dial (fig. D-2). This will clean the orifice. Contamination in the barrel or orifice can be

removed by dismantling the tensiometer and flushing the parts with distilled water. Do not use detergents to clean the barrel. Dry thoroughly and reassemble. Be sure to replace the Vaseline seal.

Clean the sample container (beaker) removing any residual oil by flushing with Chlorothene. (Benzene or petroleum naphtha can be used; however, they are flammable.) Allow solvent to evaporate, then wash in detergent, and rinse thoroughly in cold tap water followed by distilled water. Place beakers in an inverted position over a clean dry towel.

f. Test Procedure.- Apparatus, sample, and distilled water should be at a preferred common temperature of 25 EC (77 OF) plus or minus 1 EC (plus or minus 1.8 EF). Absolute control at this temperature usually is not possible in the field; however, test as close to this temperature as possible. Definitely avoid large temperature changes particularly when testing comparison samples taken at specified time intervals.

**NOTE2:** This method is a comparatively rapid procedure particularly applicable for field use. Therefore, filtration adds an undesirable extra step. Also, it is anticipated that oil samples drawn from electrical equipment in the field will not contain heavy oil sludge, such as may be found in samples taken at the end of laboratory oxidation tests, which would interfere with the determination of IFT.



(1) Replace the 50-mL beaker used to establish the volume of the calibration drop with a beaker of the same capacity. Pour the unfiltered oil sample into this beaker to a depth of at least 25.4 mm (1 in). Place beaker containing oil sample on the tensiometer table, lower tensiometer until the orifice tip is immersed about 12.7 mm (0.5 in) into the oil.

(2) Record the dial reading. Expel one drop of water. Record the dial reading. Subtract the first reading from the second reading and record the difference. (Volume.)

(3) Expel about three-fourths of the volume of water found in paragraph (2) above and allow this drop to age for 30 seconds.

(4) Expel, slowly, enough water to cause the drop to fall so that the total time is between 45 and 60 seconds.

(5) Note the volume of water in the drop in terms of divisions on the scale. This reading gives the IFT of an oil of average density.

Example:

Scale reading before expelling drop  
of water = 40.0  
divisions

Scale reading after expelling drop of  
water = 86.6 divisions

Volume of water in  
drop,  $86.6 - 40.0 = 46.6$  divisions

Approximately three-  
fourths of 46.6 = 35.0 divisions

The scale reading after expelling the trial drop was 86.6. divisions on the upper scale. This corresponds to 36.6 divisions on the lower scale. Add 35 divisions (approximately three-fourths of the volume of the trial drop) to the scale reading (36.6 divisions). Turn dial to 71.6 and allow drop to age 30 seconds. Then turn dial slowly until drop of water falls into oil. The total elapsed time from the time the drop starts to form on the orifice tip until it drops from the tip should not exceed 60 seconds.

Scale setting at 60  
seconds = 83.0 divisions

Minus scale setting at  
0 second = -36.6  
divisions

Equals volume of  
water in drop = 46.4 divisions

Volume x 0.001 equals  
IFT of the oil = 0.0464 N/m

(6) If more accurate test results are desired or if the field IFT of an oil is 0.02 N/m (20 dyn/cm) or less, a sample of the oil should be sent to the Denver Office, Attn D-3743, for a more accurate and detailed analysis.

## APPENDIX E

### DOBLE TESTS OF LIQUID INSULATION WITH MH AND M2H TEST SETS

**E-1. General.-** In order that sample of liquid insulation may be tested with the Doble test sets, a special cell has been constructed which is essentially a capacitor utilizing oil or askarel as the dielectric. Provided with the cell is a container in which the cell may be housed and carried when not in use. Figure E-1 shows the cell and the metal carrying pail.

The cell holds approximately 1 L (1 qt) and should be filled until there is about 19.0 mm (0.71 in) of liquid above the top of the cylinder inside the cell. The cell should be set on a reasonably level base

so that the surface of the liquid will be approximately level. The cover should be properly seated.

The test connections are made as shown in [figure E-2](#). The hook of the high-voltage cable should be connected to the handle on the cover. The cold guard ring of the cell which is fastened to the cover. The outer cylinder should be to the UST (ungrounded specimen tester). A clearance of at least 25.4 mm (1 in) should be maintained between the cable hook and the cell guard ring so that flashover will not occur between these parts.

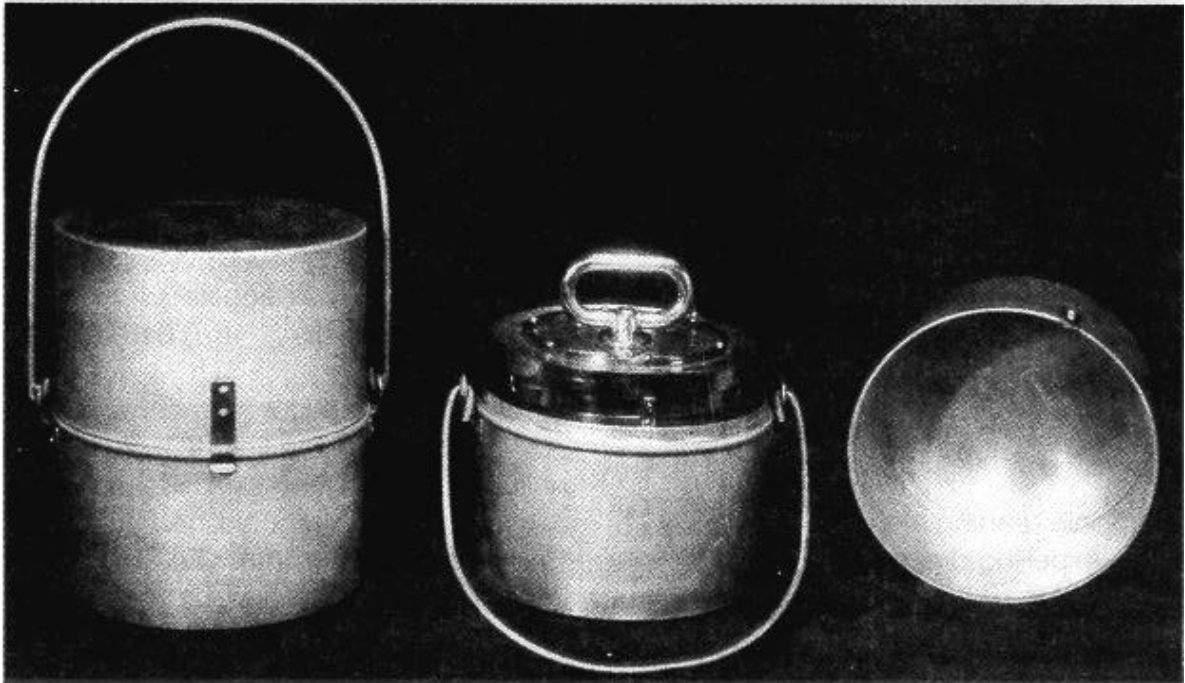


Figure E-1. - Liquid-insulation cell with metal carrying pail.



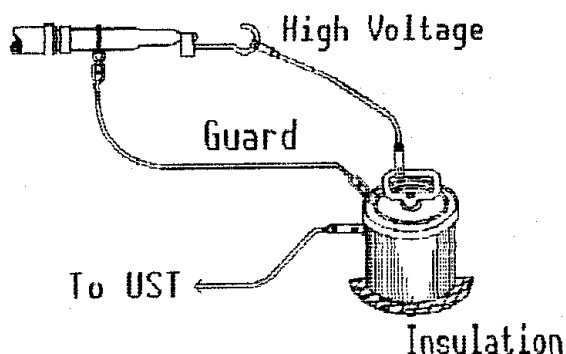


Figure E-2. -Liquid-insulation cell connected for testing

The test voltage should be gradually raised to 10 kV. As the spacing between the plates of the cell is about 4.8 mm (3/16 in), the sample should not break down at these voltages unless it is in very poor condition. Meter readings should be taken and the power factor calculated.

When drawing a sample of liquid insulation from a transformer or circuit breaker, care should be taken to obtain a representative sample. Let sufficient liquid drain through the pipe and valve so that any dirt or water lodged in the pipe will be drained before filling the test cell.

Air bubbles, water, and other foreign material are the usual cause of breakdown in the cell. If the sample is allowed to stand in the cell for a short time before the test is made, the entrapped air will have a chance to work out and foreign particles to settle to the bottom. If there is an insufficient amount of liquid in the cell, sparkover will take place above the liquid level.

Immediately after the sample has been tested, its temperature should be taken

while still in the cell. The power factor should then be corrected to 20 EC (68 EF) using the multipliers in the columns headed "Oil and Oil-Filled Power Transformers" or "Askarel and Askarel-Filled Transformers" as the case may be, in the table in section 1 under Variation of Power Factor with Temperature of the Doble "Type MH Instrument Manual."

Obviously, the test cell should be cleaned thoroughly every time a different sample is tested. Generally speaking, so long as the same type of liquid is to be tested, the cell is cleaned adequately by washing it with a good, new sample or a portion of the sample to be tested. If the cell is to be used to test askarel after its used with oil (or vice versa), a nonflammable solvent can be used for cleaning. Then the cell should be dried. In general, however, thorough washing with a portion of the sample to be tested should be adequate. It is better not to wipe out the container with rags, as cotton fibers, etc., may be left in the cell and consequently may affect the breakdown voltage of the sample.

When transporting the cell, it should be packed carefully to prevent damage. The packing in which the cell is shipped may be utilized for this purpose.

**E-2. OIL.-** Good, new oil has a power factor of 0.05 percent or less at 20 EC. Higher power factors indicate deterioration and/or contamination with moisture, carbon or other conducting matter, varnish, Glyptal, sodium soaps, asphalt compounds, or deterioration products. Carbon or asphalt in oil can cause discoloration. Carbon in oil will not necessarily increase the power factor of the oil

unless moisture is also present. It is suggested that the following serve as guides for grading oil by power factor tests.

- a. Oil having a power factor of less than 0.5 percent at 20EC is usually considered satisfactory for service.
- b. Oil having a power factor between 0.5 and 2 percent at 20EC should be considered as being in doubtful condition, and at least some type of investigation should be made.
- c. Oil having a power factor of over 2 percent at 20EC should be investigated and either reconditioned or replaced.

The above-mentioned guides may be elaborated on by saying that good, new oil has a power factor of approximately 0.05 percent or less at 20EC and that the power factor can gradually increase in service to a value as high as 0.5 percent at 20EC without, in most cases, indicating deterioration to warrant investigation. When the power factor exceeds 0.5 percent, an investigation is indicated. The question of what decision to make regarding disposition of the oil depends on what is causing the high power factor. Dielectric strength tests should be made to determine the presence of moisture. The necessity for further tests will depend to a large extent on the magnitude of the power factor, the importance of the apparatus in which the oil is used, its rating and the quantity of oil involved.

**E-3. ASKAREL.-** Good askarel has a power factor of 0.05 percent or less when

new. Higher power factors indicate contamination with moisture, carbon or other conducting matter, asphalt compounds, varnish, Glyptal, gasket materials, and/or other foreign matter or deterioration products. It is suggested that the following serve as guides for grading askarel by power factor tests.

- a. Askarel having a power factor of less than 0.5 percent at 20EC is usually considered satisfactory for service.
- b. Askarel having a power factor between 0.5 and 2.0 percent at 20EC should be considered as being in doubtful condition, and at least some type of investigation should be made.
- c. Askarel having a power factor of over 2 percent at 20EC should be investigated to determine the cause of the high-power factor. If the high-power factor is caused by water or other conducting matter, free chlorides, or high neutralization number, the askarel is probably an operating hazard. If the high-power factor is not due to these causes, it is probably not an operating hazard, except that when the power factor is quite high, it may result in excessive heating of the device in which it is used. Care should also be taken to ensure that the high-power factor is not due to dissolving of a gasket or insulation necessary for safe operation of the askarel-filled device. High-power factor caused by askarel contamination may mask other defects in askarel-filled devices.

## APPENDIX F

### DIAGNOSTIC CRITERIA FOR GAS-IN-OIL ANALYSES OF TRANSFORMER INSULATING OIL

**F-1. General.-** Gas-in-oil analysis by gas chromatography has proven to be predictive and valuable. Some of the problems which could progress to catastrophic failures in transformers that can be detected are: arcing (often caused by loose connections within the transformers caused by vibrations); corona (electrical discharges from the winding); overheated oil (overloading of the transformer causing the insulating oil and other parts to overheat, or oil that is in poor condition and in need of reclaiming, resulting in poor heat transfer); and cellulose degradation (the insulating paper wrapping material around the coils becoming brittle and starting to deteriorate). These problems result in gas production as they start to develop and gas production increases with increasing severity of the problem.

**F-2. TRANSFORMER PROBLEMS.-** The combustible gases indicative of each of the above problems are as follows:

a. Arcing.- Large amounts of hydrogen and acetylene are produced, with minor quantities of methane and ethylene. If arcing involves cellulose, carbon monoxide and carbon dioxide may also be formed. Key gas: acetylene.

b. Corona.- Low-energy electrical discharges produce hydrogen and methane with small quantities of eth-

ane and ethylene. Comparable amounts of carbon monoxide and carbon dioxide may result from discharges in cellulose. Key gas: hydrogen.

c. Overheated oil.- Decomposition products include ethylene and methane, together with smaller quantities of hydrogen and ethane. Traces of acetylene may be formed if the overheating is severe or involves electrical contacts. Key gas: ethylene.

d. Cellulose degradation.- Large quantities of carbon monoxide and carbon dioxide are evolved from overheated cellulose. Hydrocarbon gases, such as methane and ethylene will be formed if the problem involves an oil-impregnated winding insulation. Key gas: carbon monoxide.

**F-3. BACKGROUND.-** Since initially we had no experience in interpretation of data from gas chromatography analysis of transformer insulating oils, we relied on those who had experience, such as Doble Engineering and Analytical Associates, Inc. Our experience to date has prompted slight departures from the earlier criteria to take into account the operational conditions, degree of maintenance, and climatological conditions of solar radiation and air temperatures. For example, we look at 15 parts per million acetylene as being the signal of abnormal transformer

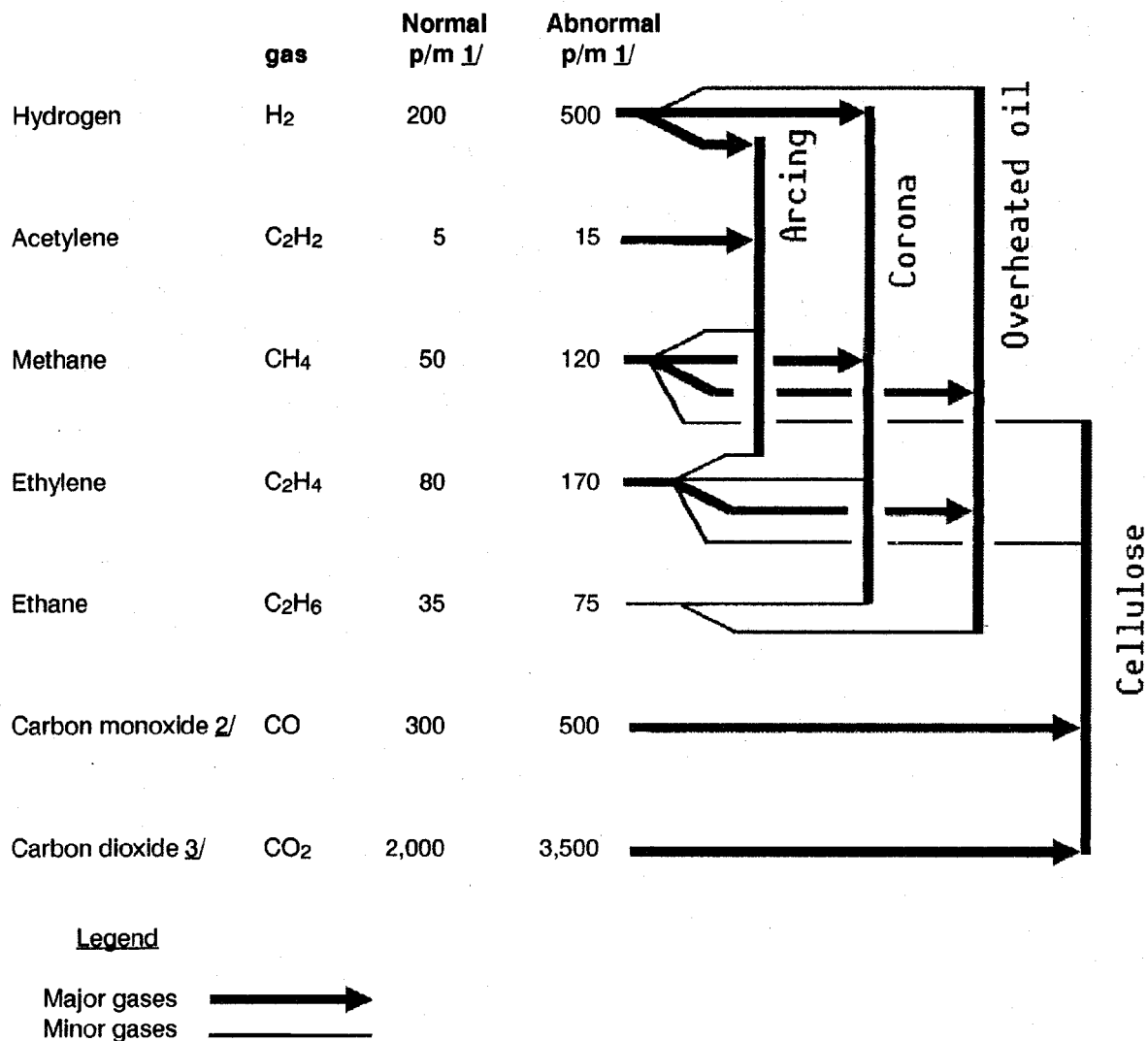
performance, rather than the 50 parts per million used by some others. Also, a degree of judgment is exercised in applying the criteria. As more experience and a backlog of data builds up to indicate trends, the criteria will be modified to become more meaningful.

**F-4. DIAGNOSTIC CRITERIA.**- Our present criteria for gas chromatograph analysis are shown in [figure F-1](#). Gas concentrations in the region between "normal" and "abnormal" may indicate need for increased monitoring to detect trends in gas production of a particular transformer. In this region, static or falling concentrations would indicate no problem. Rising concentrations suggest increasing potential for a catastrophic failure and require some more intense surveillance.

When one or more gases are found to exceed the "abnormal" level, prompt confirmatory tests usually would be recommended. However, the diagram of fault indications is interpreted in the light of known operating conditions for the particular transformer and the judgment of the oil specialists. The Denver Office has prepared a spreadsheet program for recording, diagnosing, and plotting the results fo gas-in-oil test results. It may be used on Lotus 1-2-3, Version 2.01 or 2.2. Copies of the program may be obtained from the Assistant Commissioner - Resources Management, Denver Office.

To be more in line with utility practices, Reclamation has lowered its limits for CO and CO<sub>2</sub> as shown on [figure F-1](#).

On the left are gases the oil specialist looks for in the gas-in-oil analysis. On the right are possible origins for these gases. When these gases exceed the levels shown in the middle columns, the analyst uses the transformer history, the type of gases present, as well as the relative amounts, to determine any indication of transformer problems.



1/ p/m = parts/million by volume (gas/liquid)  
 2/ Previous limits for CO were 500 and 700 p/m  
 3/ Previous limits for CO<sub>2</sub> were 2,000 and 10,000 p/m

**Figure F-1. - Gas volume limits used in interpretation of gas chromatograph analysis for transformer insulating oil.**

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